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Ecological indicators of the effects of multiple farming activities in a Mediterranean High Nature Value Farmland

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Resumo

Devido às pressões antropogénicas de uma população em constante crescimento, as alterações na intensificação dos usos do solo são, hoje, uma ameaça séria à biodiversidade. Os sistemas agroflorestais apresentam-se como locais com usos de solo bastante diversos e sujeitos a alterações frequentes. Muitas destas alterações, tais como a transformação de espaços florestais em campos para agricultura ou pastoreio intensivo, e a consequente adição de produtos químicos, acabam por ameaçar os ecossistemas terrestres e aquáticos e consequentemente diminuir a qualidade dos serviços que estes sistemas oferecem.

Na bacia do Mediterrâneo o montado estabelece-se como um dos principais sistemas agroflorestais. Em condições normais, o montado apresenta-se como um sistema agro-silvo-pastoril, onde os usos do solo vão desde o pastoreio intensivo ou extensivo, à produção de cortiça, entre muitas outras atividades. Nas zonas próximas do montado, outras atividades agrícolas, tais como a agricultura intensiva, irrigada e fertilizada também estão presentes. Para além disso, estes sistemas têm também um grande interesse conservacionista. Uma elevada biodiversidade de fauna e flora acompanhado pelo risco de degradação iminente, torna o montado um local de elevada importância ecológica, estando assim classificado como Hotspot de biodiversidade e *High Nature Value Farmland* (HNVF). O montado pode ser dividido em *montado* de sobro e *montado* de azinho, dependendo se a espécie arbórea dominante é o sobreiro, *Quercus suber*, ou a azinheira, *Quercus ilex*. Em ambos os ecossistemas, a paisagem é tradicionalmente caracterizada por ter uma pequena densidade de Quercus e um subcoberto composto por herbáceas e arbustos. No entanto, a abundância de bens e serviços que providencia e a grande diversidade de usos do solo são grandes atrativos económicos para o Homem, que assim realiza um conjunto de práticas que muitas vezes exercem uma pressão excessiva sobre estes ecossistemas e colocam em risco a sua biodiversidade.

Uma dessas práticas é o pastoreio, que na região ribatejana e alentejana é predominantemente de gado bovino. A atividade deste tipo de gado é altamente impactante a vários níveis, desde a depleção do subcoberto vegetal e consequente aparecimento de solo nu, ao pisoteio que degrada solos, destrói a vegetação e impede a germinação das sementes, até à emissão de compostos gasosos azotados como a amónia que altera as propriedades químicas do solo, cria eutrofização nas massas de água e promove a criação de compostos azotados na atmosfera. Outra das práticas que pode ocorrer no local ou em zonas agrícolas na envolvente destes sistemas agroflorestais é a aplicação de fertilizantes, normalmente ricos em compostos azotados e fosfatados, e que com determinadas condições climáticas podem ser transformados em compostos voláteis tais como a amónia, sendo muito tóxicos para a biodiversidade em concentrações elevadas. As práticas florestais, com ênfase no descortiçamento e no desmatamento, são igualmente impactantes na medida em que o primeiro torna os sobreiros mais suscetíveis a pragas e doenças e o segundo altera a estrutura e composição da vegetação, o que posteriormente afeta os solos e o microclima. Por fim, importa ainda referir que se prevê que as alterações climáticas terão um efeito negativo a médio e longo prazo nestes sistemas agroflorestais. As previsões para a região da bacia do Mediterrâneo apontam para a ocorrência de menores valores médios de precipitação e maiores valores médios de temperatura o que, numa zona já de si seca e quente, irá provocar a ocorrência de secas extremas, contribuindo para o aumento das áreas desertificadas e erodidas.

É então premente que se desenvolvam ferramentas que permitam balancear a gestão e exploração económica dos ecossistemas agroflorestais de *High Nature Value Farmland* (HNVF) com a procura por manter a estrutura e funcionamento ecológicos para que estes continuem a providenciar os bens e serviços de regulação e manutenção tão necessários para a gestão dos recursos a longo prazo.

Assim, o objetivo deste trabalho é determinar as influências que as várias atividades agrícolas exercem sobre a biodiversidade que estes ecossistemas albergam e assim criar uma ferramenta de gestão a ser aplicada nestas áreas. Para isso, efetuou-se a análise de dois indicadores ecológicos, sendo eles os líquenes epifíticos e os escaravelhos coprófagos. Essa escolha deveu-se ao facto de ambos os grupos serem sensíveis à eutrofização, especialmente às alterações das concentrações de azoto (na atmosfera e nos solos, respetivamente) e disponibilidade de nutrientes, bem como à alteração da estrutura da floresta, permitindo-nos assim avaliar os possíveis impactos dos vários usos do solo na biodiversidade do *montado*. Desta forma é possível fazer uma gestão que otimiza a conservação da biodiversidade e o retorno económico proveniente das atividades agrícolas.

O estudo foi efetuado na companhia das Lezírias, situada a este da Reserva Natural do Estuário do Tejo. A companhia das Lezírias engloba uma área de aproximadamente 18 mil hectares, e é composta por diversas parcelas de terreno com diferentes usos de solo, incluindo uma área considerável de *montado* de sobro. Esta propriedade é monitorizada há já dezenas de anos pelo que existem dados detalhados de todas as atividades agroflorestais que nela ocorrem. Foi assim possível criar um gradiente do uso do solo a partir desses dados. Esse gradiente variava entre a exclusão de pastoreio (máximo de 19 anos sem pastoreio) em algumas parcelas, até ao pastoreio máximo de 2,82 cabeças de gado bovino por hectare, por ano. Foram posteriormente selecionadas 18 parcelas onde foram analisadas as comunidades de líquenes epifíticos em 113 sobreiros e posicionadas 90 armadilhas iscadas com excrementos de bovino para captura de escaravelhos coprófagos.

A estrutura das comunidades dos indicadores ecológicos e respetivas variáveis dos grupos funcionais foram correlacionadas com diversos fatores ambientais, incluindo diversos parâmetros do solo, a humidade da canópia (Normalized Difference Moisture Index – NDMI), a temperatura à superfície da paisagem (através dos valores de *Land Surface Temperature* - LST), as perturbações locais causadas pelo pastoreio, pela fragmentação e pelo tráfego motorizado no interior da Companhia e as perturbações causadas pela agricultura intensiva nas zonas adjacentes à área de estudo. A escolha destes fatores ambientais, em detrimento de outros, deveu-se ao facto de eles terem frequentemente um papel mais relevante nas variações da composição e estrutura das comunidades. Essas variações são provocadas pelos usos de solo existentes na área de estudo e zonas adjacentes, quer ao nível da poluição, eutrofização, alterações na vegetação e microclima. Assim, recorrendo a uma abordagem multi-taxa ao nível local e da paisagem poderemos identificar quais as principais ameaças para a biodiversidade existente.

Ao nível dos líquenes epifíticos, mais sensíveis às alterações atmosféricas, a proximidade de explorações agrícolas intensivas revelou-se como os fator mais importante para explicar as diferenças na abundância dos grupos funcionais deste indicador ecológico, entre as parcelas estudadas. Tal se deve à aplicação intensiva de fertilizantes com compostos azotados nos arrozais e culturas temporárias de regadio, como os campos de milho, adjacentes à área de estudo. Parte destes compostos azotados, tais como a amónia, são dispersados pelo vento e acabam por se depositar no interior da área de *montado*, acabando por impactar a biodiversidade de líquenes existente. A intensidade do pastoreio, com exceção da área com maior intensidade (zona de concentração de gado bovino) de pastoreio, não mostrou ser a fonte principal de impacto na biodiversidade dos líquenes, muito provavelmente devido a esse pastoreio ser extensivo e de baixa intensidade. Isto leva a que a quantidade de amónia produzida esteja abaixo do nível crítico, a partir do qual as comunidades de líquenes respondem a este tipo de perturbações. Também não se identificou nenhuma associação entre as comunidades de líquenes e a proximidade às estradas, pois estas registam níveis muito baixos de tráfego e consequentemente não são fontes de poluição. Em relação aos escaravelhos coprófagos, foram detetados alguns padrões apesar do suporte estatístico ter sido baixo. Tal poderá ter-se devido à amostragem não ter coincidido

com o pico de atividade deste grupo (mais no final da Primavera). Mesmo assim, conseguimos identificar algumas associações de diversos parâmetros do solo, áreas de má qualidade e a humidade da canópia com as comunidades de escaravelhos. Diversos parâmetros do solo e as áreas menos propícias à existência de escaravelhos coprófagos revelaram ser os factores mais importantes para explicar as mudanças nas comunidades deste indicador.

É fundamental para a manutenção da biodiversidade, dos bens e serviços do *montado* que a sua gestão tenha em conta a intensidade do pastoreio. Os resultados mostram, por exemplo, que a partir das 3 cabeças de gado por hectare de pasto, por ano, deixa de ser possível manter os níveis de biodiversidade de líquenes iguais aos de zonas não pastoreadas. É também necessário ter em atenção aos usos de solo e intensidades dos mesmos em zonas adjacentes às áreas de *montado*, tais como as zonas agrícolas fertilizadas. Assim, zonas agrícolas intensivas devem estar localizadas a pelo menos 1 km de zonas com importância para a conservação. Este estudo pretende assim construir uma ferramenta de gestão capaz de perceber quais os impactos que as múltiplas atividades agrícolas exercem sobre os sistemas de *montado*.

Palavras-Chave: *Montado*| Indicadores Ecológicos | Líquenes | Escaravelhos | Gestão Ambiental

Abstract

Changes in the type and intensity of land-use are two of the main factors threatening biodiversity worldwide, especially in ecosystems with diverse land uses, like agro-forestry ones. These changes, driven by the need to keep up with the provision of goods and services might be damaging to our ecosystems and at the long-term increase the risk of disrupting the services they provide.

Nowadays, two of the most impacting land uses are farming and livestock breeding, due to water and air pollution and consequent eutrophication on soils and water bodies, thereby reducing the health and biodiversity of terrestrial and aquatic ecosystems. In the Mediterranean basin, one of the most iconic agro-forestry systems is the montado area. These areas are agro-silvo-pastoral systems that sustain diverse activities within it such as livestock breeding and cork production. Around it we can also find other agriculture activities, such as cereals and vegetables crops. Traditionally, most activities within the montados are performed with low intensity. As a consequence, these ecosystems were considered to have high interest for conservation, being label as High Nature Value Farmlands. However, when management is more intense, it can impact biodiversity and the services that these ecosystems provide. Climate changes will also add an extra pressure on montado ecosystems, due to changes in precipitation and temperature. Thus, it is vital to improve the management and the practices that occur inside and close to these areas. Our general aim was to build a management tool to understand the impacts of multiple farming activities in High Nature Value montado areas. This was done considering the effects of grazing intensity and its exclusion within the woodlands, and simultaneously the effects of nearby intensive agriculture. The tool was based in the use of lichens and coprophagous beetles as ecological indicators of these impacts, using different biodiversity metrics, in air and soil compartments, respectively.

A study was done in Companhia das Lezírias, a state farm with almost 18 thousand hectares, divided in dozens of plots with different land uses intensities, thus creating a gradient of intensity ranging from plots in grazing exclusion (maximum of 19 years excluded) to plots with maximum grazing intensity of 2.82 cattle heads per hectare, per year. We focused on analysing two ecological indicators, epiphytic lichens and coprophagous beetles. Both are sensitive to eutrophication, nutrients availability and changes in vegetation structure, thus being suitable indicators to evaluate possible impacts from the different land uses in montado.

All functional groups of epiphytic lichens showed, primarily, an effect of the nitrogen compounds deposition from the fertilizers used in crops surrounding the study area. Those fertilizers end up being dispersed by the wind and deposited inside the montado area, thus impacting lichens biodiversity. Coprophagous beetles' communities showed to be associated with local soil characteristics, with the amount of surrounding habitats with poor suitability to host beetles and the vegetation moisture. Thus, cattle's grazing was not a major impact source for the selected ecological indicators. This was likely due to the low intensity grazing.

We concluded that lichens are good ecological indicators to access impacts caused by nitrogen compounds from fertilizers inputs in nearby farming activities as they responded well to the impacts caused by the nitrogen deposition. In turn, coprophagous beetles' communities' didn´t allow us to determine the impact of any of the farming activities present in the study area. Nonetheless, if further studies take in consideration the soil characteristic of the sampled sites, beetles may reveal to be good ecological indicators of multiple farming activities.

Keywords: *Montado* | Ecological Indicators | Lichens | Beetles | Environmental Management

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1. Introduction

The increase in the world's population is exerting an huge pressure in ecosystems worldwide, particularly from changes in land use type and intensity, mining ecosystems capacity to provide us with their services (Jaramillo & Destouni, 2015; Wu, 2008)**.** Agriculture, either through crop or livestock, causes significant impacts, including soil and water eutrophication (Jaramillo & Destouni, 2015). All these impacts have impacts on biodiversity, reducing the health and integrity of the ecosystems (Falcucci et al. 2007; Flynn et al. 2009; Haines-Young, 2009; Reidsma et al. 2006); UNEP, 2002).

1.1. The impact of agriculture activities

With the rise of the world population and economic power in the last century, the cattle sector production increased quite a lot, both in beef and dairy cattle (**Figure 1.1.1**). According to Food and Agriculture Organization of the United Nations (2017) from 1961 to 2014, cattle increased by 500 million heads to a total of 1,5 thousand millions heads total. According to the *Instituto Nacional de Estatistica* (2016), in 2016, Portugal had slightly more than 1,6 million heads, a small increase compared to the 1,5 million heads in 2014. These numbers contrast with most of the developed countries, especially in Europe, where numbers have stabilized or even decreased (Organization of the United Nations, 2017). Portugal also experienced an intensification of the cattle sector due to a decrease in the number of cattle farms and a contrasting increase of the number of cattle heads per area, which means that each farm has more cattle density than before (Costa, 2015; Instituto Nacional de Estatistica, 2016).

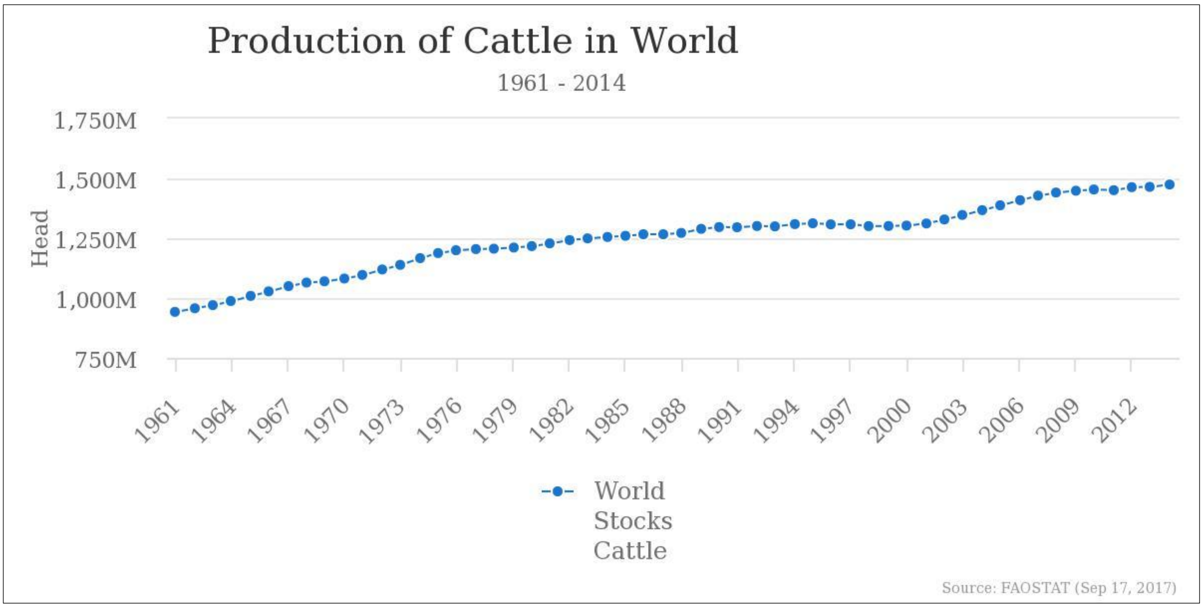

Figure 1.1.1: Evolution of the number of cattle heads worldwide (1961-2014). Source: Organization of the United Nations (2017)

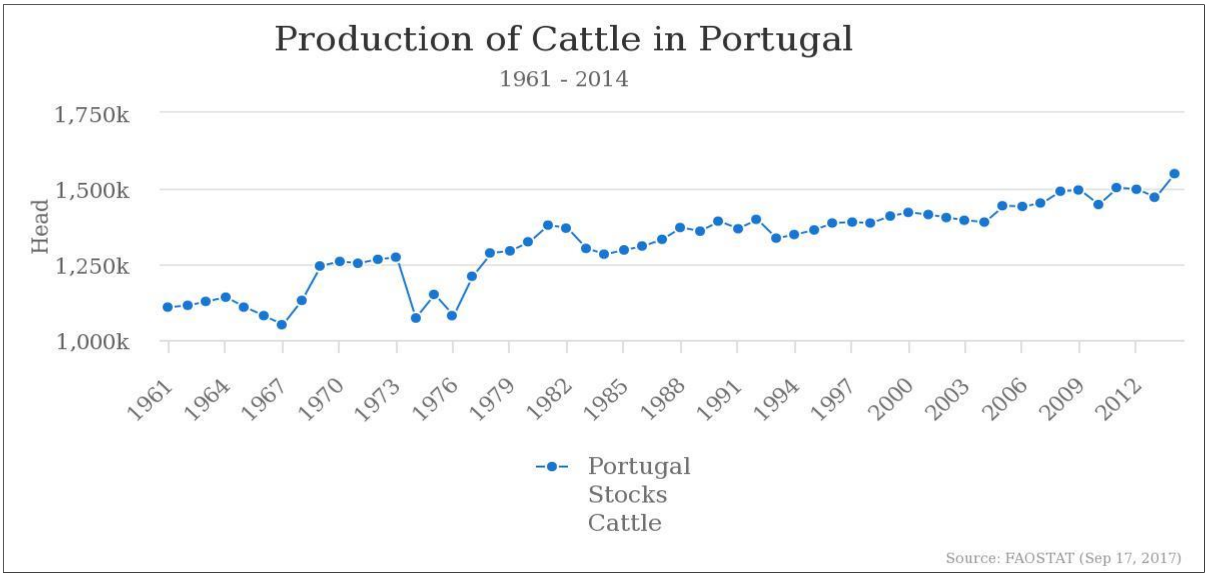

Figure 1.1.2: Evolution of the number of cattle heads in Portugal (1961-2014). Source: Organization of the United Nations (2017)

According to FAO (2014) and Thornton (2010), we expect a future decrease in cattle products consumption in developed countries. Nevertheless, cattle production is still increasing in some developed countries, like Portugal (**Figure 1.1.2**) and in underdeveloped countries due to further demographic rise and better financial conditions of people living in those countries. In undeveloped countries, where legislation is often bypassed, and knowledge isn't well spread throughout society, there is a high chance of over exploitation of the environment by this sector, leading to overgrazing. Over-grazing occurs when the amount of cattle in a given area is higher than the capacity of that area to provide feedstuff. This phenomenon changes the ecological properties of the ecosystem, and the degree of that change depends upon the grazing intensity and the characteristics of the grazing area. Those changes can be seen in the air, soil and vegetation, being inter-connected between them.

The production of cattle emits massive amounts of ammonia/ammonium and methane. Ammonia/ammonium, is toxic and has direct impacts in biodiversity through soil, water and atmosphere compartments (Bussink, 1992; Ishler, 2004). In turn, methane is a gas that contributes to the greenhouse effect. Over-grazing leads to an increased bare soil percentage and susceptibility to erosion by rain and wind (Risch et al. 2007). Roots removal also potentiates a loss of soil structure (FAO, 2003). Trampling affects soil by compacting it, decreasing its infiltration rates and the nutrients dissolved in it, making the soils poorer and drier (Sharrow, 2007; Vandandorj et al. 2017). On top of that, vegetation works as a carbon dioxide sink and consequently, when removed, that reservoir is destroyed (FAO, 2015). According to Concostrina-Zubiri et al. (2017), in a study conducted at *Companhia das Lezírias*, biocrusts abundance in grazed sites was very low compared to ungrazed sites, due to trampling and browsing by cattle. Over-grazing also produces changes in the composition and structure of the vegetation. That effect is due to the quick consumption of the vegetation by the cattle, which then promotes fast growth plant species rather than the slow growing ones (Ishler, 2004). Germination, seedling survival rates and growth are also affected both by consumption and trampling (Listopad et al. 2018; Wassie et al. 2009). Losses of aboveground plant biomass also have a negative effect in the nutrients cycle because less organic matter is produced and decomposed (FAO, 2003). The most noticeable change of over-grazing is the transformation of the landscape towards more open space and low vegetation density, when compared to sites with low intensity grazing or with grazing exclusion. The soil becomes more exposed and consequently more susceptible to erosion and desertification.

Establishment of grazing exclusion areas is a well-known and used management technique, to stop or mitigate ecosystems degradation and, on the long term, restore it. One of the benefits of this management practice is the transformation of the vegetation structure, with grasses being gradually replaced by shrubs and woody plants (Listopad et al. 2018). This transformation enhances vegetation cover, aboveground biomass production and higher biodiversity levels (Bugalho et al. 2011; Castro & Freitas, 2009; Listopad et al. 2018; Yan & Lu, 2015). A change towards denser and higher vegetation increases water retention in the soil and blockage of direct sun light, reducing soil and air temperature (Concostrina-Zubiri et al. 2017). These microclimatic changes induced by grazing exclusion generate differences in both fauna and flora communities. A study conducted at *Companhia das Lezírias*, showed that is in the first 5 years after exclusion is when the most dramatic changes in the vegetation occur (Listopad et al. 2018),. During this time interval, the distribution of shrub vegetation increased greatly while herbaceous- vegetation declined. After 15 years of exclusion, they could observe that shrubs height and tree diameter had increased significantly, meaning that this management practice can be very effective to regenerate vegetation structure.

Nitrogen is abundantly present in earth's atmosphere as nitrogen gas (Erisman et al. 2007). Nitrogen gas (N_2) cannot be used directly by living organisms. For that, nitrogen must become reactive (Nr), either by a combination of thunderstorms and rains or by fixation by free or symbiotic bacteria with plants, through an enzyme called nitrogenase (Galloway & Cowling, 2002; LeBauer & Treseder, 2008). Reactive nitrogen is highly important to all living beings due to the fact that it is vital for the formation of organic compounds like nucleic acids for DNA formation, ATP molecules for energy storage and amino acids for proteins formation (Erisman et al. 2007; Galloway & Cowling, 2002). Nitrogen is a limiting factor for agriculture production (Bal et al. 2012; Monaghan et al. 2005; Tilman, 1987), but production of Nr in large scale was only possible in the beginning of the 20th century. At that time, German chemists Fritz Haber and Carl Bosch developed an artificial process of nitrogen fixation, using hydrogen and atmospheric N_2 in order to create ammonia (NH_3). From that ammonia it was possible to produce large quantities of nitrogen fertilizers, such as ammonium nitrate, in an industrial scale (Encyclopædia Britannica, 1998). The use of fertilizers allowed humankind to enhance the production of more food (Roberta Forti & Henrard, 2016).

Fertilizers have, however, being generally over applied, especially in crops and pastures. The unused reactive nitrogen leaches into the soil, causing changes in its chemical and physical properties, turning soils more acidic, and triggering changes in biodiversity and abundance of fungal and microbial communities (McDowell et al. 2004; Bowden et al. 2004; Galloway & Cowling, 2002; Ramirez et al. 2010). The flora is also affected because nitrophytic species or species with fast growth rates end up getting advantage over species more sensitive to high nitrogen levels or with slow growth rates, causing modifications in the vegetation structure and composition. A significant part of these compounds ends up leaching to water bodies and ground water masses like rivers, lakes, underground reservoirs or oceans. This can cause eutrophication and consequently losses in water quality and aquatic biodiversity (Bal et al. 2012; Johnson et al. 2005). When ammonia volatizes, it ends up settling in soils, water masses and vegetation close to the source, either by dry or wet deposition (Asman et al. 1998; Bal et al. 2012; Pinho et al. 2009; Ruisi et al. 2005). After an input of fertilizers , the volatilization speed depends on the temperature, presence of precipitation, air velocity, humidity and soil type and pH (Bussink, 1992; Ishler, 2004) while the deposition speed changes according the precipitation, the air velocity and the size/density of the surrounding vegetation (Asman et al. 1998;

Bal et al. 2012). In the atmosphere, the ammonia can cause the formation of aerosols, depletion of the ozone layer in the stratosphere and others (Galloway et al. 2003; Galloway & Cowling, 2002; Ishler, 2004).

On the long term, high and continuous inputs of fertilizers cause substancial changes in biodiversity and, ultimately, changes the landscape (Bal et al. 2012; Galloway et al. 2003; Gough et al. 2000; Ramirez et al. 2010; Tilman, 1987; UNEP, 2014).

1.2. *Montado* and its landscape

One of the ecosystems where human management is more important and where land uses types are more diverse is the *montado*. The *montado* is an agro-silvopastoral system, an woodland structurally similar to a savannah, but is human-managed, being grazed by cattle, pig, sheep and goat. Grazing co-exist with extensive crops and a large number of other activities such as tourism, hunting and cork production, being the last one the most profitable (Associação Portuguesa da Cortiça, 2017; Pereira & da Fonseca, 2003). This ecosystem extends along the Mediterranean basin, occurring in countries like Portugal, Spain, Morocco, and others. In Portugal, *montado* areas occupy 756 thousand hectares, 34% of all his world extension, of which, 84% are located in the Alentejo region (Associação Portuguesa da Cortiça, 2017).

While the *montado* present in the innermost regions of Portugal is dominated by *Quercus ilex* (Holm-oak), closer to the Atlantic it is dominated by *Quercus suber* (Cork-oak). This happens because *Quercus suber* requires higher moister levels to develop than *Quercus ilex* (Attorre et al. 2015). *Montado* areas are characterized by having a Mediterranean climate, very dry and hot during the summer and with mild and rainy winters (Encyclopædia Britannica, 2016). The singularity of this climate allows this Mediterranean region to host a high faunistic and floristic diversity, with many endemic species. The main singularity of these ecosystems is their flora. They usually have small tree density, with the rest of the vegetation being composed by grasses and shrubs (Pereira & da Fonseca, 2003; Rodrigues, 2008). In these ecosystems, where water is a limiting factor, the vegetation evolved to create strategies to counteract that limitation (Haines-Young, 2009; Ramos et al. 2015). The vegetation starts growing in October and reaches its peak during spring, taking advantage of the greater availability of water and then, during the high temperatures and dryness of the summer, it dries up, becoming very susceptible to fire. The unique and high biodiversity and the degradation risk (more than 70% of the original habitats) associated to these ecosystems to the Mediterranean basin is recognized and led to its classification as one of the major biodiversity hotspots worldwide, especially with regard to *montado* habitats (Bugalho et al.2011; Myers et al. 2000; Xavier & Martins, 2000) (**Figure 1.2.1**).

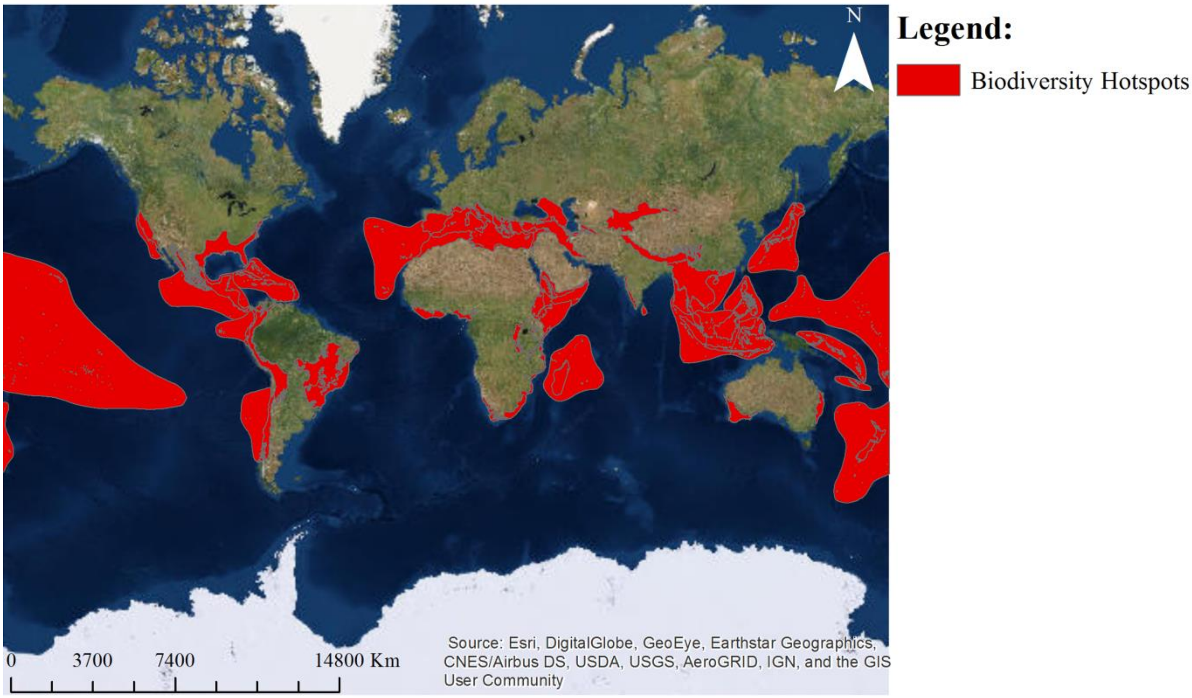

Figure 1.2.1: Geographical distribution of biodiversity hotspots worldwide. Source: Myers et al (2000)

The *montado* is designated, according to the European Union, as a High Nature Value Farmland (HNVF) (**Figure 1.2.2**). This concept has started in the beginning of the 1990's and refers to agricultural areas of high conservation value and whose agricultural management practices are fundamental to the maintenance of high biodiversity levels (Keenleyside et al. 2014). *Montado* landscape have, for years, been in a balance between the ecological value and economic interests from landowners, trough low intensive practices like livestock grazing, cork production and others. However, changes in the traditionally performed practices in exchange for other more profitable or simply the intensification of the original practices have led to a disruption of that balance, putting in danger the ecosystem health. The *montado* is a striking example of land-sparing conservation policies, where the same area supports economical yield and high biodiversity. Therefore, these areas can only subsist when the economic and ecological interests are taken in account and management policies and evenly balanced between both.

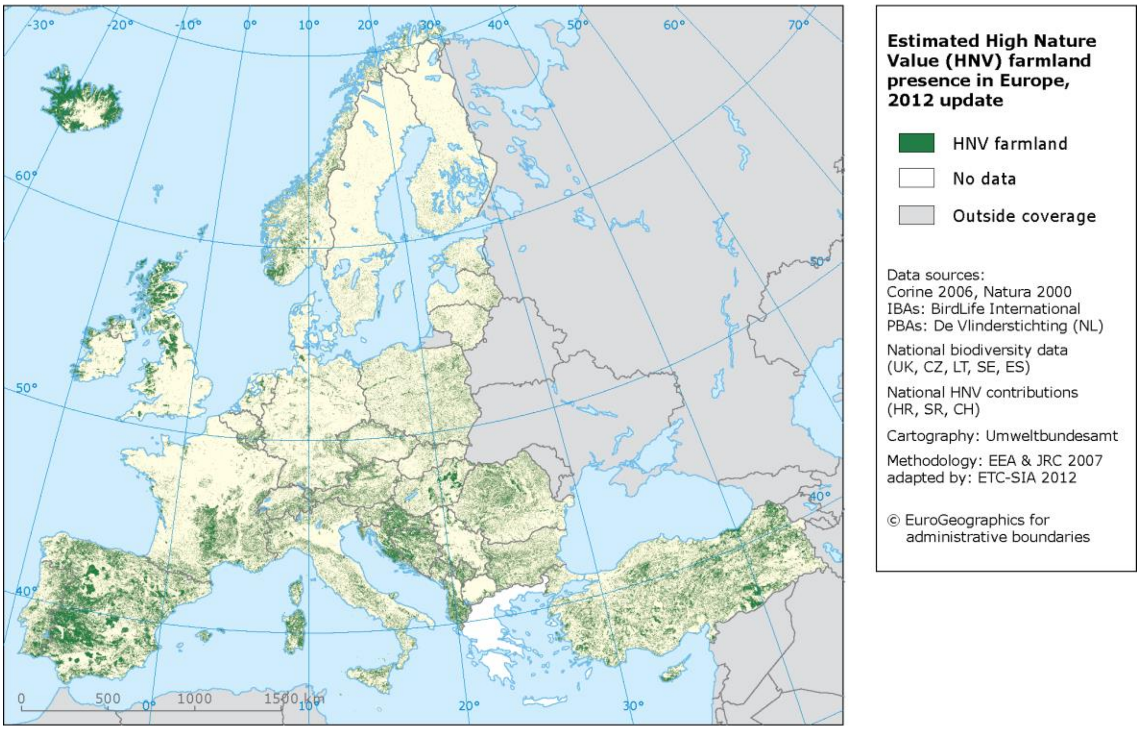

Figure 1.2.2: Distribution of the High Nature Value Farmland (HNVF). Source: European Environmental Agency (2017)

However, changes in the intensity of management can promote large changes in the ecosystem structure and function. Local intensification can lead to vegetation losses, soil impoverishment and render trees more weakened and susceptible to pest and diseases (Attorre et al. 2015; Cancela et al. 2013; Ministério da Agricultura, 2013). These can be further intensified by ongoing climate changes, with a reduction in the average annual precipitation levels and the rise of the average annual temperature (Haines-Young, 2009; IPCC, 2007; Ministério da Agricultura, 2013). Additionally, the landscapes around *montado* ecosystems can also experience intensification, with the presence of irrigated and fertilized crops and intensive cattle rising. It is therefore vital to establish a balance between intensification in the surrounding areas of the *montado* and the protection of its biodiversity and its services. To do that, we must provide farmers and politicians with important and reliable information about the impacts of multiple farming activities taking place in and around *montado*. For that we need to measure the impact of the agriculture activities that take place in the *montado* and in the surroundings of the *montado* and ecological indicators could be a good choice.

1.3. Ecological indicators

One of the ways to study the impacts of disturbances on ecosystems is by using ecological indicators. Two very common approaches focus on changes in their taxonomic composition, changes in their functional groups, or on both. According to Peñuelas et al. (2004), ecological indicators are "measurable characteristics of the structure (e.g., genetic, population, habitat, and landscape pattern), composition (e.g., genes, species, populations, communities, and landscape types), or function (e.g., genetic, demographic/life history, ecosystem, and landscape disturbance processes) of ecological systems." Ecological indicators started being used during the last century and the number of studies using them multiplied ever since (Matos et al. 2017) . This is due to the many advantages of their use compared to other, more analytical methods (e.g. chemical assays and the measurement of physical parameters). Their responses integrate the direct effect of the impact sources on the ecosystem. Besides, we have more sampling sites at lower cost and with a higher resolution (Branquinho, 2001; Branquinho et al. 2015). The preference for the use of ecological indicators was due to the fact that they are cost-effective without compromising the efficiency and reliability while measuring/describing the effects of different environmental changes on ecosystems structures. Moreover, information provided by ecological indicators is simple and therefore can be easily communicated to practitioners and decision makers. Several metrics can be used to measure the effects of both structure and functioning of *montado* ecosystems as High Nature Value Farmland (HNVF). Taxonomy based metrics are commonly used (Giordani, 2007; Gotelli & Colwell, 2001; Jorge M. Lobo & Martín-Piera, 2002; Pinho et al. 2003). Furthermore, though taxonomy based metrics may respond, they do not provide insights on the drivers of the changes in those communities and may offer no reliability when trying to compare geographical distant sites (Mouillot et al. 2014). For that reason, we also used shifts in the communities and functional trait based metrics. Functional trait metrics were used successfully in several studies before, namely in this type of ecosystems (Gotelli & Colwell, 2001; Jorge M. Lobo & Martín-Piera, 2002; Pinho et al. 2012; Pedro Pinho et al. 2011). So, we adopted a functional trait approach, by classifying each species based on their characteristics (traits) regarding their response to the expected impacts addressed in our study (Laureto et al. 2015; Mouillot et al. 2014). Species with similar characteristics are then grouped into functional groups and used in functional trait metrics.

In this study, to evaluate the impact of multiple farming activities in a High Nature Value *montado* area, we decided to select coprophagous beetles and epiphytic lichens as our ecological indicator organisms. Beetles were used as proxy of the effects in the soil compartment. They are known indicators of the quantities of manure produced by cattle (Jorge M. Lobo et al. 2006; Peck & Howden, 2017; Slade et al. 2007), and thus nitrogen excreted in the soil. Once in the soil such nitrogen is volatilized to the air. Lichen communities were used as a proxy of the effects in the air compartment. They have a long history as ecological indicators of excessive nitrogen in the atmosphere (Pinho et al. 2009, 2011, 2012), taking into account the system capacity to handle the excessive nitrogen in the soil.

1.3.1. The use of epiphytic lichens biodiversity as ecological indicators

Epiphytic lichens are organisms that result from a symbiosis between a fungus and green algae and/or cyanobacteria, growing over a plant substrate. In this symbiosis, the fungus provides water and minerals, and serves as the main anchor and structure of the organism, while the green algae and/or cyanobacteria provide nutrients from photosynthesis (Conti & Cecchetii, 2001). Lichens absorb nutrients and water directly from the atmosphere. They balance their water and nutrient content with the surrounding environment, due to their inability to regulate its content. During dry periods, they become inactive, only re-activating when the surrounding environment gets more humid. These characteristics are what make them such excellent ecological indicators of environmental changes in the atmosphere. The use of lichens as ecological indicators of atmospheric changes is vast, and a lot is known about the evaluation of the effects of nitrogen pollution and climate and its effects on ecosystems worldwide (Frati et al. 2008; Hauck, 2010; Llop et al. 2012; Matos et al. 2015; Pinho et al. 2012) Some species of lichens may react even to small changes in the atmospheric concentration of pollutants, serving as an early warning system for this type of threats and as to monitor air quality.

Lichens have traits related to their growth form, main reproduction type, and tolerance to eutrophication, substrata pH, irradiation and aridity, and thus can be divided into functional groups. These traits are all thought to be important in mediating their response to the potential impacts that multiple farming activities might have in *montado*. Eutrophication tolerance is a useful trait for nitrogen pollution studies (Lopes, 2010; Pinho et al. 2011; VanHerk, 2001). Oligotrophic lichens only tolerate low levels of nutrients and, therefore, are very scarce close to pollution sources like barns, high-traffic roads or factories. Nitrophytic lichens can manage to thrive even in sites with high nutrients concentration due to the fact that there are tolerant to even high levels of nutrients. Mesotrophics are in between the two described before. Air pollution from ammonia sources (VanHerk, 2001) and dust from arid areas help raise pH of epiphytic lichens substrate, like tree bark, making the pH trait useful to identify dusty areas (Frati et al. 2008; Giordani & Malaspina, 2016). Growth form (**Figure 1.3.1.1**) reflects the way lichens intercept particles and water in the atmosphere (Matos et al. 2015). Therefore, this trait is good to analyse eutrophication and aridity levels. Main reproduction trait translates lichens response to stress, due to the fact that they tend to reproduce sexually when in stressed environments, thus being good indicators of environmental stress (Martínez et al. 2012). Irradiation trait translates lichens tolerance to sites with more direct sunlight, being suitable traits for climate and vegetation structure differences (Munzi et al. 2014). Lastly, the aridity trait translates the climate conditions, making this trait useful in climate changes studies.

Figure 1.3.1.1: Examples of the three lichens growth forms. From left to right: foliose broad lobe (*Xanthoria parietina*), foliose narrow lobed (*Physcia adscendens*); and fruticose (*Usnea rubicunda*). Photos by: P. Matos and P. Pinho

Though lichens have a long history as ecological indicators, only a few studies (Pinho et al. 2008; Pinho et al. 2012) used epiphytic lichens to evaluate the effect of multiple land uses in *montado* ecosystems.

1.3.2. The use of coprophagous beetle's biodiversity as ecological indicators

Coprophagous or dung beetles (Coleoptera, Scarabaeoidea) have been roaming earth since the Mesozoic period. They feed on animal faeces, both during larval and adult phase (Bertone et al. 2006). The majority of the species of this group have higher activity during spring and summer seasons, due to warmer temperatures (Rainio & Niemela, 2003). The odour released by the faeces attracts these beetles that then travel to them either by moving on the soil surface or by flying, depending on whether they are winged or not. Fast traveling to where the faeces are located is very important because they feed preferentially on fresh ones (Holter, 2016). Other than feeding, they also use dung to lay their eggs and feed their larvae. These species are very important for the ecosystems, even more in grasslands with livestock, for a variety of reasons. One of them is due to their ability to remove the dung from the soil surface. Without beetles and other coprophagous species, those same dung can stand up to 4 years before completely disappearing (Whipple, 2011). This service is fundamental for livestock pastures because cattle don't graze near their own dung. This way, beetles increase decomposition rates of the dung, allowing livestock to graze freely in the entire pasture. Dung beetles also help spread out the dung along the soil surface and underground, increasing fertility. The activity of coprophagous beetles also helps aerate and increase infiltration of water in the soils, improving both physical and chemical characteristics of the soil (Abot et al. 2012; Bertone et al. 2006; Campos & Hernández, 2015; Correa et al, 2016; Howison et al. 2016; Nichols et al. 2008; Yamada et al. 2007). Removal of dung by coprophagous beetles also hinders livestock pests and flies to proliferate because they no longer have dung where they can lay their eggs and grow their larvae. Beetles also destroy their eggs by direct mechanical damage with their mouthpieces (Bertone et al. 2006; Campos & Hernández, 2015; Correa et al. 2016; Losey & Vaughan, 2006; Nichols et al. 2008; Whipple, 2011). Last but not least, they have also an important role on seed dispersal (Correa et al. 2016; Nichols et al. 2008; Whipple, 2011). For these reasons, coprophagous beetles have been the target of many ecological studies being a suitable indicator group when assessing the impact of grazing activities and land use changes (Braga et al. 2013; Lobo et al 2001).

Coprophagous beetles can be separated into three different functional groups (**Figure 1.3.1.2**), related to the method of dung manipulation trait (Milotić et al. 2017). Tunnelers (paracoprids) dig tunnels below the dung, grabbing small amounts of it and placing them along the tunnel walls. Dwellers (endocoprids) live inside or on top of the dung and rollers (telecoprids) build small balls of dung and then roll them to other places (Bertone et al. 2006; Campos & Hernández, 2015; Yamada et al. 2007). This trait can be very useful in studies of soil and vegetation characteristics because while rollers and tunnelers are highly dependent on the soil and vegetation structure, dwellers do not seem so dependent (Chandra & Gupta, 2012; Rainio & Niemela, 2003; Whipple, 2011). Presence or absence of wings can also be a useful trait to use in vegetation structure studies because beetles with wings have difficulties to fly in sites with closed vegetation. These constraints aren´t felted by the wingless beetles that move along the ground.

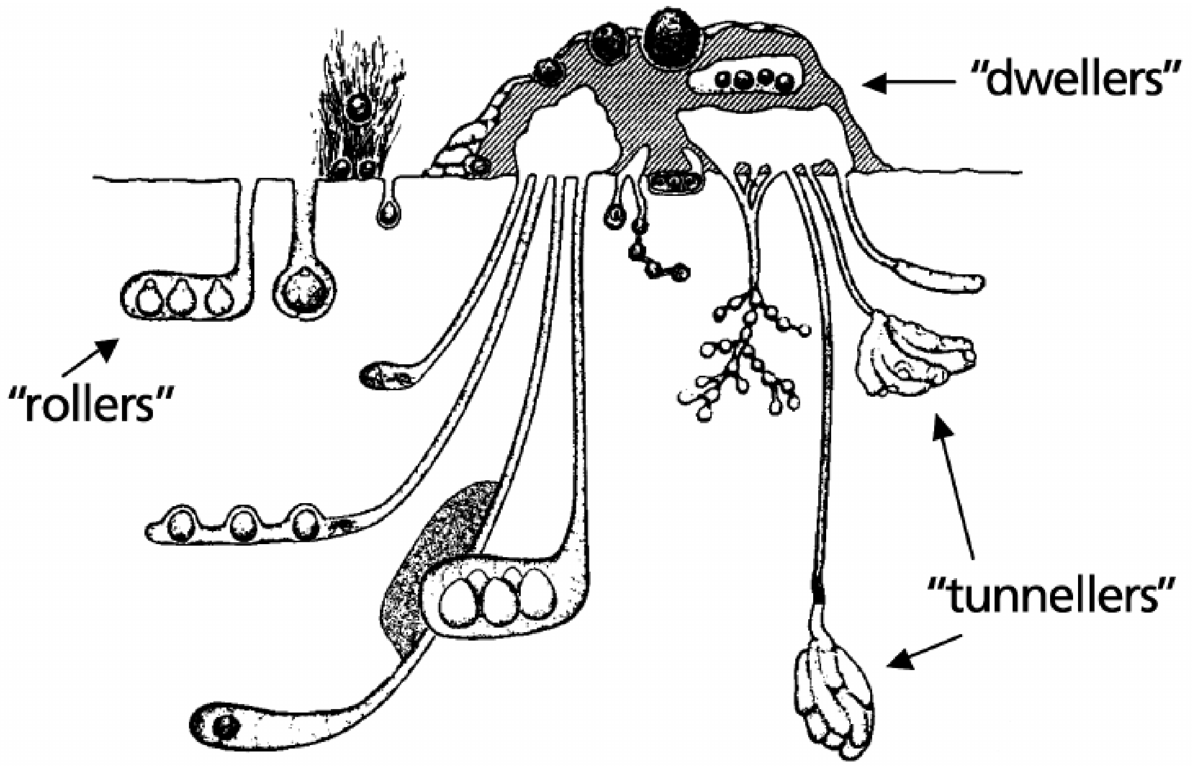

Figure 1.3.2.1: Coprophagous beetles' functional groups, regarding the dung manipulation method trait**.** Source: K. D. Floate (2011)

Intensification of grazing also may affect them (Buse et al. 2015; Howison et al. 2016; Lobo et al. 2006), either positively by the production of more dung patches, that provide food and shelter, or negatively by trampling or mechanic abrasion from the grazing activity.

1.4. Objectives

Recognizing the importance of a sustainable use of the *montado* to maintain its biodiversity and ecosystem services, and taking into consideration the threats posed by land-use intensification, our general aim was to build a management tool to understand the impacts of multiple farming activities in High Nature Value *montado* areas. This was done considering the effects of grazing intensity and its exclusion within the woodlands, and simultaneously the effects of nearby intensive agriculture. The tool was based in the use of lichens and coprophagous beetles as indicators of these impacts, using different biodiversity metrics, in air and soil compartments, respectively.

We also aim at answering these questions:

1) Can we apply both ecological indicators in the context of the impacts of the multiple farming activities;
2) Which are the best metrics, in both indicators, to measure the impact of the multiple farming activities;
3) Which activities have the most impact;
4) Which solutions can be taken to reduce those impacts.

2. Methodology

2.1. Study area

This study was conducted in the “Charneca” site of Companhia das Lezírias (CL) (**Figure 2.1.1**), a state-owned propriety where multiple agricultural activities co-exist within an 18000 ha area, forming a patch with multiple land-uses in a relatively small area. In the “Charneca” site the ecosystem is dominated by *montado* ecosystems, characterized by the presence of *Quercus suber* and small grasses and shrubs (ILTERN, 2017). The climate is Mediterranean with a strong seasonally, with dry hot summers and winters with mild temperatures and precipitation. Average annual temperature is 17.5 ºC and average annual precipitation is 600 mm (averages 1931–1960; Pinho et al. 2012).

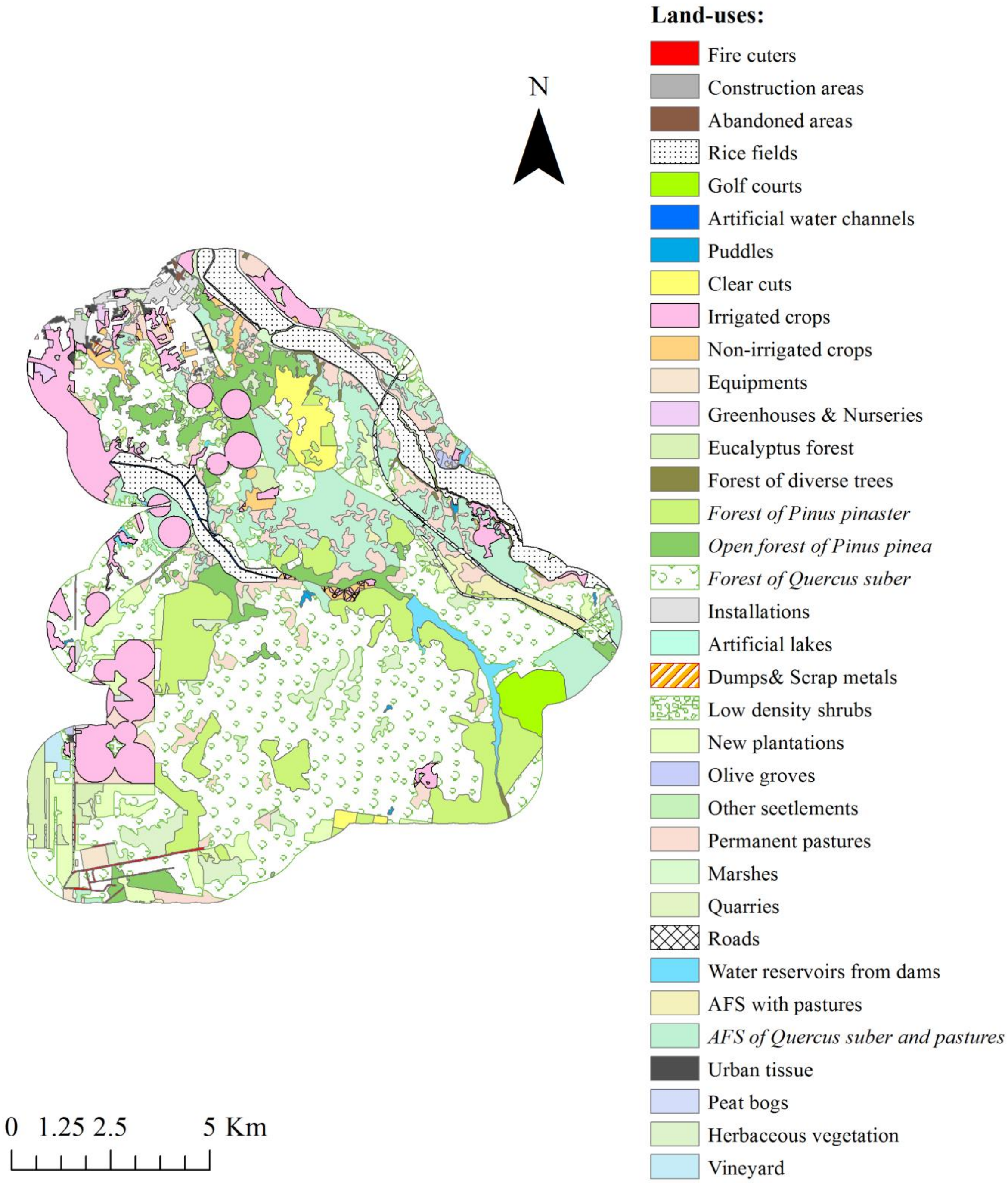

Figure 2.1.1: Map of the main land-uses present in the "Charneca" site inside "Companhia das Lezírias". Map based on information provided by (Direção-Geral do Território, 2016). (AFS stands for Agro-forestall systems)

Varied economical activities are developed inside CL property, like cork harvest (each 9 to 12 years), different crops, viniculture, beef cattle, hunting and others. Cattle grazing is done in a low-intensity, extensive regime, with rotation of the cattle by multiple pastures sites. Those sites are separated from each other by wood and barbed wire fences, preventing cattle to leave their designated site. Nearby, other land uses like irrigated and fertilized crop cultures, viniculture and nature tourism also take place. CL is also located very closely to the Tagus Estuary Nature Reserve and is included in the Natura 2000 network, being covered by a Special Protection Zone (ZPE) and Sites of Community Importance (SCI) (ICNF, 2017). CL is also included in the International Long Term Ecological Research Network (ILTER), a scientific research network, spread around the world and focused on the gathering of data to improve the understanding of global ecosystems over the long term. This is important because there are several other studies previously conducted in the same (or similar) areas, making it easier to gather and share information with other researchers (ILTER, 2017).

2.2. Sampling design

For this study we focused on the plots occupied by *montado*. These plots are managed by the company and vary from long-term grazing exclusion (since the last 19 years) to grazing with multiple intensities. From the 42 plots, 17 were in a grazing exclusion regime, ranging from just 1 to 19 years of grazing exclusion. For the remaining, CL provided us the data on cattle heads (number of animals per year per hectare), and also about the normal use of fertilizers in nearby cultures (rice and corn fields with, respectively, 122 Kg(N)/ha/year and 275 Kg(N)/ha/year).

To select sampling sites from the total number of plots with *montado* (n=43), we performed a stratified sampling design. Stratification was done according to grazing intensity in each site, using the following formula:

Grazing Intensity = [1/9*07-08+1/8*08-09+1/7*09-10+1/6*10-11+1/5*11-12+1/5*12-13+1/4*13-14+1/3*14-15+1/2*15-16-(exclusion years)].

In this formula, 07-08; 08-09; 09-10; 10-11; 11-12; 12-13; 13-14; 14-15 and 15-16 refer to the annual grazing intensity levels for each of the plots. The increasing importance attributed to the recent year was chosen to give extra weight to recent years' grazing intensity. The subtraction of the grazing years was chosen to differentiate between sites with grazing exclusion for many years. Overall, the values of the Grazing Intensity Index ranged from -19 to 390. The highest values correspond to the sites with higher presence of cattle in the recent years, the lowest values to sites excluded from grazing for the longest time. From there, we defined 9 classes of values, being the plots ordered according to their grazing intensity value. After ordering the plots, we selected 2 plots in each class, giving priority to plots already chosen in a previous work performed in the CL property (Listopad et al. 2018). The remaining plots were chosen randomly. The total number of plots selected was 18 (**Figure 2.2.1)**.

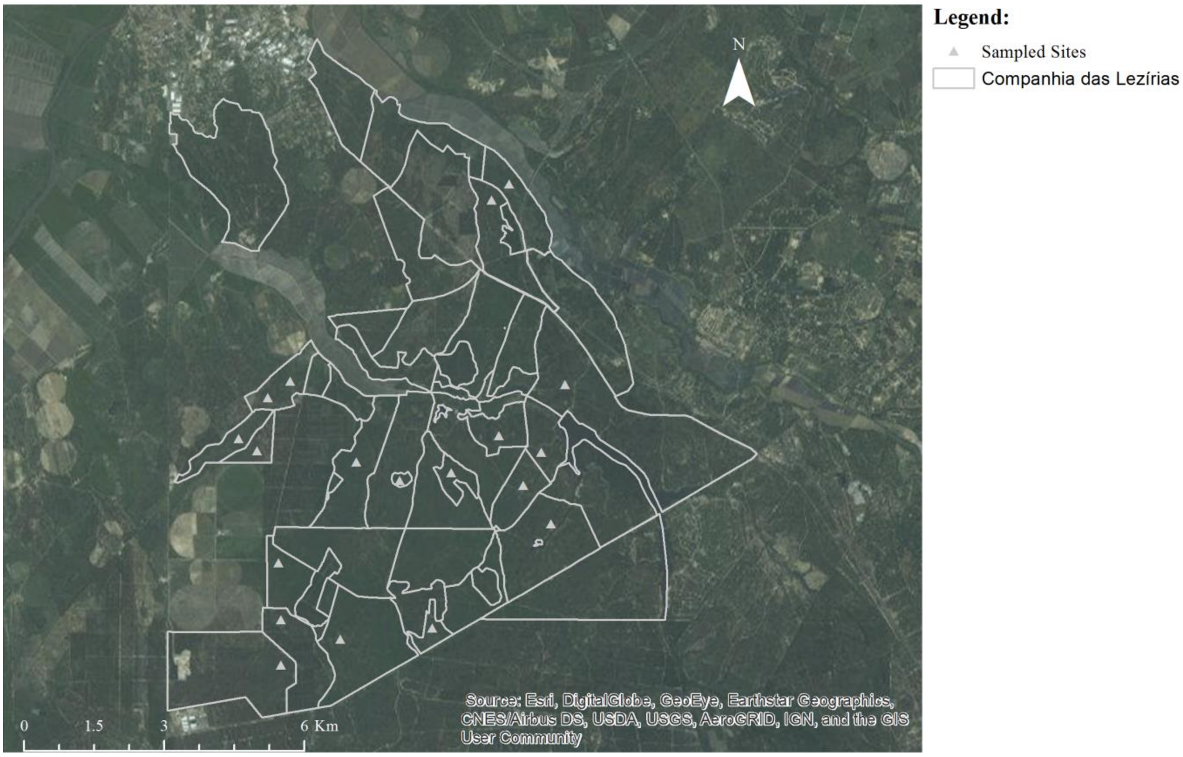

Figure 2.2.1: All CL plots with *montado*, the 19 sampling sites (tringles) and the 42 plot divisions. Note that one additional site was selected for lichen sampling only (due to time-constrains) due to the area within the plot having much more heavily grazing intensity levels than the centroid, and was added to the sampling.

Within each plot, the geometric centroids were selected for sampling, ensuring that it was located at more than 250 metres from another plot, at more than 50 metres from any road and that the selected sites had vegetation cover similar to the rest of the plot. Note that one additional site was selected for lichen sampling only. This resulted from field verification, that a specific area within the plot with the highest cattle density presented fixed cattle feeders. This area within the plot was much more heavily grazed by cattle than the centroid, and was added to the sampling. However, due to time-constrains, only lichens could be sampled in this area. In the selected sampling sites, sampling of lichens and beetles was carried out. These sites were further characterized regarding environmental factors like land surface temperature (LST), grazing exclusion years, distance to the nearest road, habitat suitability, Normalized difference moisture index (NDMI) and several soil characteristics (soil texture, soil thickness, soil actual permeability and soil potential permeability)

2.2.1. Epiphytic lichens sampling

In this study, we focused on the analysis of epiphytic macro lichens rather than on the conjugation of macro and micro lichens, in order to study the air compartment. This option was taken because, as previously stated by (Grogan & Barreto, 2005; Pinho et al. 2008), macro and micro lichens have a similar response to these impact sources and therefore the response of one of them is usually similar to the response of both of them together (Bergamini et al. 2005). More, sampling macro lichens is easier and faster, saving time, both in the field and in the laboratory. On top of that, macro lichens identification requires far less experience and knowledge than crustose lichens identification.

Sampling was conducted from 3 to 7 of April, 2017. The six *Quercus suber* closer to each centroid were selected, keeping in mind that they had to: 1) have a perimeter equal or superior to 50 cm but inferior to 250 cm; 2) have a trunk as vertical as possible; 3) with undamaged bark or any visible signs of disease (Asta et al. 2002; Pinho et al. 2015). The amount of sampled Quercus individuals was lower than recommended, due to time constrains although other studies also used a lower number of sampling individuals without compromising their work (Pinho et al. 2009, 2011; Ruisi et al. 2005).

The sampling procedure was conducted by vertically placing a 50 cm by 10 cm grid, divided in 5 equal squares of 10 cm per 10 cm (**Figure 2.2.1.1**). The grid was placed in unharvested *Quercus suber* bark, at a minimum height of 100 cm and fixed by pins.

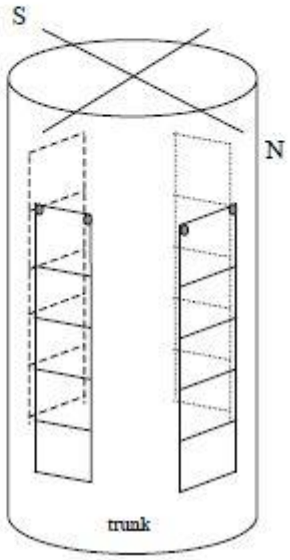

Figure 2.2.1.1: Sampling grid for lichen sampling composed of 5 contiguous quadrats. The grid is placed in four different positions accordingly to the four cardinal points (north, south, east, and west). Source: Asta et al. (2002)

We then proceed to the identification of all epiphytic macro lichens in each square of the grid, either by naked eye or with a magnifying lens. This process was repeated 4 times in each tree moving the grid to match each cardinal point (North, South, East and West). Individuals that couldn´t be identified in the field, were collected and taken to the laboratory for posterior identification. Identification was done using Smith et al. (2009) and Martellos (2010) identification keys. Tree perimeter at breast height was also recorded. In total, 113 trees were sampled, out of 114 possible. This was due to the fact that, in one of the plots, there weren't enough trees suitable to be sampled. Species frequency in each site is the average number of quadrats each species occurs in a tree (minimum of zero and maximum of 20). Lichens diversity value (LDV), an abundance measurement, was calculated for each sampling site (by adding the species mean frequency in each site) and species richness were also calculated and used as metrics.

The community weighted mean (CWM) single-trait metric was computed afterwards (Matos et al. 2015) for each functional group and was used in statistical analysis. Lichens traits and respective functional groups (**Table 2.2.1.1**) were chosen based on several other studies using the same and other traits (Matos et al. 2015; Martínez et al. 2012; Pinho et al. 2011; Llop et al. 2012; Herk, 2001); Pinho, 2010; Frati et al. 2008; Munzi et al. 2014) that they are appropriate indicators of the potential impacts of the multiple farming activities that occur in our studied area. Information regarding functional traits was collected from Nimis (2016). Each lichen species is classified (from 1 to 5) based on his preferences to eutrophication, aridity, solar irradiation, pH and also reproduction and growth form type. We selected the highest classification to provide the information of that species tolerance to each factor.

Table 2.2.1.1: Traits and related functional groups following (Nimis, 2016; Smith et al. 2009). *When species were classified within two or more classes, we chose the highest class to translate the species tolerance.

Trait	Functional Group	Description	Symbol
Growth form	Foliose broad lobes	Partly attached to the substrate with a leaf-like form and broad lobes	Fob
	Foliose narrow lobes	Partly attached to the substrate with a leaf-like form and narrow lobes	Fon
	Fruticose	3D-like structure, attached by one point to the substrate with the rest of the thallus standing out from the surface of the substrate	Fr
Reproduction type	Asexual	Mainly asexual reproduction with soredia or isidia like structures	Asx
	Sexual	Mainly sexual reproduction by spores	Sex
Eutrophication tolerance*	Oligotrophic	Tolerance to very weak eutrophication levels	Oligo
	Mesotrophic	Tolerance to weak eutrophication levels	Meso
	Nitrophytic	Tolerance to very high eutrophication levels	Nitro
pH substrate tolerance*	Sub-neutral	Tolerance from sub-acid to sub-neutral pH	S-Neu
	Basic	Tolerance from slightly basic to basic pH	Bas
Irradiation tolerance	Sun-exposed	Tolerance to sun-exposed sites	Expo
	Very high direct solar irradiation	Tolerance to sites with very high direct solar irradiation	Direct
Aridity tolerance*	Mesophytic	Tolerance to mesophytic conditions	Mesop
	Xerophytic	Tolerance to xerophytic conditions	Xerop

2.2.2. Coprophagous beetles sampling

We also focused on the analysis of coprophagous beetles in order to study the soil compartment. Sampling was conducted during the first two weeks of March. Days 1, 2 and 3 were destined to the placement of 5 dung baited pitfalls closed to each centroid, in a total of 90 pitfalls. Each pitfall was placed 10 m away from the others, in a 40 m straight line. Pitfalls consisted of 12 cm diameter plastic cups with 13.5 cm height. They were buried until the top of the cup matched the soil surface. The dung bait was positioned over the plastic cup, involved in a thin fabric and fixed by a stick. The pitfall structure was completed with a small plastic plate placed 5 cm over the top of the buried pitfall to prevent rain or detritus from falling inside it (Hortal & Lobo, 2005) (**Figure 2.2.2.1**). Ethylene glycol and dish washer detergent solution were placed inside each pitfall to capture and preserve the beetles that were trapped inside. Pitfalls were collected on 6, 7 and 8 of March so each trap would stay in the field for 120 hours.

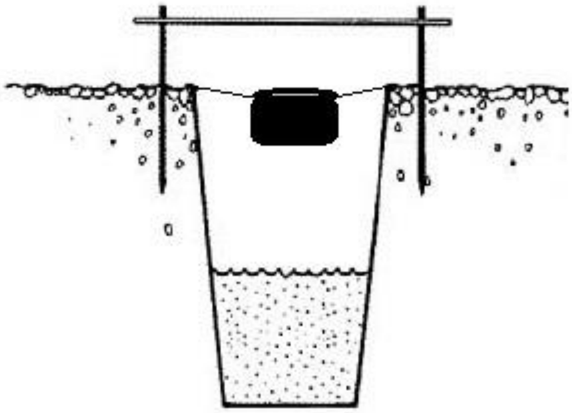

Figure 2.2.2.1: Dung baited pitfall trap. Cup is filled with a solution and buried in the soil (top of the cup matching soil surface). Dung bait is placed in the middle of the cup and a plate is placed on top of it. Source: Kotze et al. (2011) (modified)

After collecting the traps, they were brought to the laboratory and their content was individually placed inside trays. The content was examined, and beetles were separated from bi-catches and picked for further identification with the help of a stereoscope microscope. Identification of each individual was done with the help from Baraud (1992), E. B. Britton (2012), Fauna Europaea (2017), Jessop (1986) and Naturdata (2017) and also using the entomological collection of the Animal Biology Department – Faculty of Sciences, University of Lisbon. Data related to species richness and abundance of each species, inside each pitfall, was collected and used for further data analysis. The community weighted mean (CWM) single-trait metric was computed afterwards for each functional group and was used in statistical analysis. Beetles traits and respective functional groups (**Table 2.2.2.1**) were collected either by direct observation of the captured individuals (as wings presence or absence and mean species body size) or by information collected from (Baraud, 1992; Britton, 2012; Jessop, 1986) regarding the method of dung manipulation. Mean species body size was categorized in five ordinal classes (**Appendix 1**). Traits were chosen because they are known to reflect somehow the impacts of grazing activity and vegetation structure.

Table 2.2.2.1: Beetle traits and related functional groups following Baraud (1992), Britton (2012) and; Jessop (1986).

Trait	Functional Group	Description	Symbol
Dung manipulation method	Dwellers	Live inside or on top of the dung	Dwe
	Rollers	Build small balls of dung and then roll them to other places	Roll
	Tunnelers	Dig tunnels below the dung, grabbing small amounts of it and placing them along the tunnel walls	Tun
Body size classes (cm)*	[0.00 – 0.47]	Beetles with very small mean size, from 0 cm to 0.47 cm	Size A
	]0.47 – 0.95]	Beetles with small mean size, from 0.47 cm to 0.,95 cm	Size B
	]0.95 – 1.43]	Beetles with medium mean size, from 0.95 cm to 1.43 cm	Size C
	]1.43 – 1.90]	Beetles with large mean size, from 1.43 cm to 1.9 cm	Size D
	]1.90 – 2.48]	Beetles with very large mean size, from 1.9 cm to 2.48 cm	Size E
Wings presence	No Wings	Absence of wings; Inability to fly	NW
	Wings	Presence of wings; Ability to fly	W

***** Body size classes and correspondent classes' number and letter in **Appendix I**: (Mean size for each species was calculated by individually measuring the length of each beetle)

2.3 Environmental Data

Several environmental factors (**Table 2.3.1**) were chosen from data collected from different sources. They were chosen based on the possible impacts that farming activities known in the area of study may have in this ecosystem. Grazing intensity was calculated as explained before in **Section 2.2 – Sampling design**. Distance to the nearest road was measured in a GIS with high resolution imagery.

Nitrogen compounds emitted from fertilization of nearby agriculture was also calculated. Although CL *montado* have no nitrogen fertilizers inputs, nearby rice fields and temporary irrigation crops have, respectively, 122 and 275 kilograms per hectare per year of nitrogen compounds input. Therefore, we multiplied the areas of rice fields and temporary irrigation crops at each distance from each sampling site, by the amount of nitrogen compounds input per hectare, per year (in kilograms). We than calculated the amount of nitrogen potentially available from those areas, taking into consideration different distances from the *montado* sampling sites. This was done using circular areas centred in the sampling sites with radius of 500 m and 1500 m.

We classified, based on expert knowledge, each land use in terms of their adequacy to coprophagous beetles' communities, thus creating an index of fragmentation for each plot. The classification ranged between 0 and 2. Land uses classified with 0 were the ones with probable absence of coprophagous beetles while classifications with 1 were land uses with few species (species more tolerant to disturbance) and with 2 were the land uses most favourable to coprophagous beetles. Land use areas (in hectares), with the same classification, were added for each plot and then divided by the total area of 1500 meters buffer for each sampling site, thus creating a ratio for each classification inside each plot.

Land Surface Temperature (LST) values were extracted for a 50 meters buffer from each of the sampling sites. The values were calculated using an image from July 1st 2017 of the satellite Landsat 8 – TIRS10, with a spatial resolution of 100 meters. Mean temperatures for each sampling site were extracted using this method. Normalized Difference Moisture Index (NDMI) values, also called Normalized Difference Water Index (NDWI), from April and July, were extracted for a 50 meters buffer around each sampling site from a Sentinel 2A satellite, with a spatial resolution of 10 meters. April NDMI values were from April, 5 of 2017 and July values from July, 14 of 2017. NDMI values = (B8 - B11)/(B8 + B11), where B8= NIR (near infrared band) and B11= SWIR (short-wave infrared band). Soil multiple variables were obtained by using diverse topographic maps, with different scales (**Appendix II)**, either constructed from air photography or by information collected in Barata et al. (2015a, 2015b) and Pena & Abreu (2013a, 2013b).

Table 2.3.1: List of all environmental factors tested.

Environmental Factors	Description	Symbol
Grazing intensity index	Grazing intensity recorded since 2007 until 2016	Grazing Intensity
Grazing exclusion	Number of years without cattle grazing	Years of Exclusion
Distance to the nearest road	Number of meters from the sampling site to the closest road	Distance to Road
Nitrogen emissions from fertilizers (circular radius of 500m)	Amount of fertilizers inputs in land uses distanced 500m away from each sampling site	N 500m
Nitrogen emissions from fertilizers (circular radius of 1500m)	Amount of fertilizers inputs in land uses distanced 1500m away from each sampling site	N 1500m
Habitat suitability – favorable land uses	Sum of all favorable land uses for coprophagous beetles communities in a 1500m buffer around each sampling site	Habitat suitability Good
Habitat suitability – moderately favorable land uses	Sum of all moderately favorable land uses for coprophagous beetles communities in a 1500m buffer around each sampling site	Habitat suitability Medium
Habitat suitability - unfavourable land uses	Sum of all unfavourable land uses for coprophagous beetles communities in a 1500m buffer around each sampling site	Habitat suitability Bad
Land surface temperature	Translates the temperature of the earth surface	Soil Temperature
Soil texture	Soil texture in a superficial layer of 30cm. Only focuses on the evaluation of the particulates with a diameter less than 2 mm	Soil Text
Soil thickness	Effective soil thickness	Soil Thick
Soil potential permeability	Water infiltration capacity of the soil, considering the influence of the geological substrate, soil and slope	Soil Pot
Soil actual permeability	Water infiltration capacity of the soil, considering the influence of the geological substrate, soil, slope and vegetation cover	Soil Act
NDMI April	Estimated levels of moisture in vegetation during spring season	NDMI April
NDMI July	Estimated levels of moisture in vegetation during summer season	NDMI July

2.4 Statistical analysis

The analysis of the data was performed for epiphytic lichens and coprophagous beetles separately. We used Excel datasheet file (Microsoft Excel, 2010) to organize all data collected in the field and laboratory and additional data collected, regarding the functional groups CWM and taxonomic diversity (species richness and abundance) of both ecological indicators (**Table 2.2.1.1** and **Table 2.2.2.1**) and environmental factors (**Table 2.3.1**). Calculations of the community weighted mean (CWM) of both ecological indicators functional groups were done, using the FD package using R program (Laliberté et al. 2015).

Non-metric multidimensional scaling (NMS) was used individually in both species matrices to extract prominent gradients in lichens and beetles communities' composition, using PC-Ord Software, (version 7.03) (McCune & Mefford, 2016). This analysis was run in a matrix of species abundances for each group. Values were relativized to prevent biasing results and impairment of comparisons (Matos et al. 2015). Bray-Curtis distance was used, and the best NMS solution was chosen from 50 runs (with real data), each starting randomly (500 iterations per run), and evaluated with a Monte Carlo test (250 runs with randomized data). The coefficients of determination (r^2) between the original plot distances and distances in the final ordination solution were calculated to assess how much of the community variability was represented by the NMS axes (McCune, Grace & Urban 2002). Environmental factors (**Table 2.3.1**) and functional variables (**Table 2.2.1.1** and **Table 2.2.2.1**) were overlaid on the NMS ordination as correlation vectors (McCune & Urban 2002).

Individual correlations between environmental factors, functional groups variables and NMS site scores were determined using Spearman correlations (correlations were considered significant for $p<0.05$) in R program (R Core Team 2017). This was done to identify any existing significant relationship between the environmental factors, the functional variables and the NMSs sites scores.

To test the effect of the environmental factors and model them for the remaining study area that wasn't sampled (in order to provide information for stakeholders), we applied generalized linear models (GLMs) (McCullagh & Nelder, 1983). We performed GLMs for the axes from the NMS ordinations and for several functional groups. GLM computations were performed using R program (R Core Team, 2017) with function "glm" from package FD. Only variables with a significant contribution to the model were kept. Interactions between the two variables with the highest correlations with the biodiversity variables were also tested, and the interaction was kept if significant. Using the selected models, the response variables were then estimated for regularly spaced sites within *montado* landcover (distanced 500 m apart from each other's). Spatial extrapolation of models results was done using ArcGis software (version 10.5). Inverse distance weighted (IDW) was used to interpolate the dependent variable.

3. Results

3.1. Lichen diversity analyses

The analysis of lichen taxonomic diversity (species richness and abundance - LDV) revealed that from all the environmental factors tested, only N 500m and N 1500m had significant correlations with species richness (Nsp) and abundance (LDV). More specifically, N 500m showed negative correlations with Nsp while N1500 showed a negative correlation with LDV (**Table 3.1.1**).

Table 3.1.1: Spearman correlations between lichen taxonomic diversity, lichen community ordination axes (NMS1 and NMS2), and lichen trait based diversity and the environmental factors. Significance of the correlations is indicated in superscript: * = p<0.05; ** = p<0.01; *** = p<0.001; "Ns" = non-significant. The codes of the variables are explained in **Table 2.2.1.1**. GI stands for grazing intensity, YE for years of exclusion, DR for distance to the road, N500 and N1500 for, respectively, N 500m and N 1500m and LST for land surface temperature.

	Taxonomic metrics				**Trait-based metrics**													
					Growth Form			Reproduction		Eutrophication			pH		Irradiation		Aridity	
	Nsp	**LDV**	**NMS1**	**NMS2**	**Fob**	**Fon**	**Fr**	**Asx**	**Sex**	**Oligo**	**Meso**	**Nitro**	**S-Neu**	**Bas**	**Expo**	**Direct**	**Mesop**	**Xerop**
GI	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
YE	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
DR	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
N500	-0.47*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
N1500	Ns	-0.64**	0.69**	Ns	-0.57*	0.68**	-0.54*	-0.55*	0.55*	-0.72***	-0.63**	0.69**	-0.69**	0.69**	-0.52*	0.52*	-0.69**	0.69**
LST	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

The analysis of lichen communities allowed to ordinate sites according to lichen composition. The analysis suggested a two-dimensional solution. Most of the variation was explained by the first axis (85.2%), while the second one explained 12.2% of the total variance (97,3%). The minimum stress of the solution was 5.6% and lower than expected by chance (P = 0.004). **Fig. 3.1.1** shows the joint plot where environmental and functional group variables were overlaid as vectors. Only vectors with significant correlations are shown to prevent overcrowding.

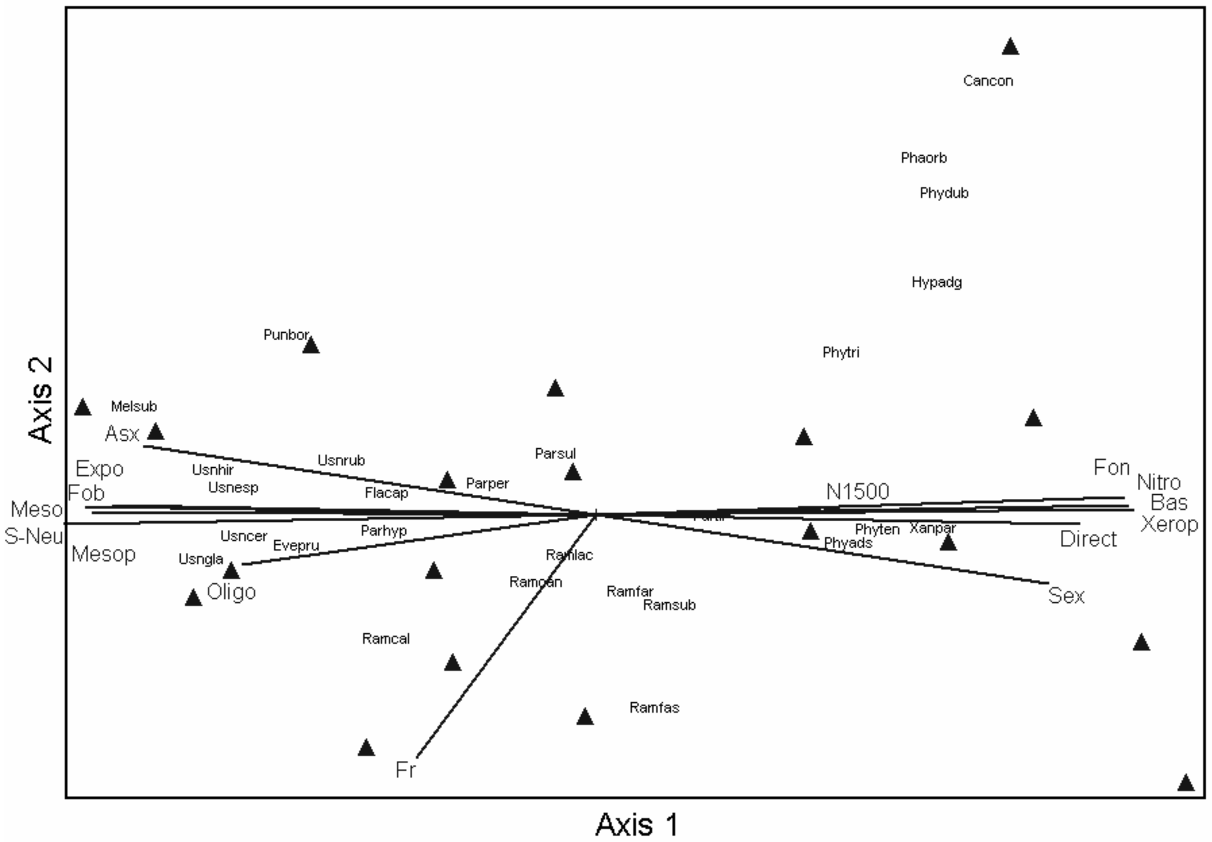

Figure 3.1.1: NMS joint plot showing the ordination of sampling sites (triangles) according to epiphytic lichen communities. The first two axes explained, respectively, 85.2% and 12.2% of the variance. Vectors represent environmental factors and lichen functional groups. Only significant variables are shown to prevent overcrowding. Environmental factors: N 1500m is the amount of nitrogen compounds emitted from fertilizers use in a 1500m buffer from each of our sampling sites. Functional group variables: Fob, Fon and Fr stand, respectively, for Foliose with broad lobe, Foliose with narrow lobe and Fruticose growth forms; Asx and Sex stands, respectively, for asexual and sexual main reproduction type; S-Neu and Bas stands for sub-neutral and basic substrate pH, respectively; Expo and Direct for sun-exposed and very high direct solar irradiation, regarding tolerance to solar irradiation. Mesop and Xerop for mesophytic and xerophytic lichens, regarding lichens aridity tolerance; Lastly, Meso, Nitro and Oligo stands, respectively, for mesotrophic, nitrophytic and oligotrophic lichens, regarding their eutrophication tolerance.

N 1500m was significantly correlated with the first axis (**Table 3.1.2**), thus this axis from lichens' ordination represents a gradient of sites with increasing nitrogen input from fertilizers. No significant correlations were found between the studied environmental factors and the second axis of the ordination. To rule out the possibility of the site in the extreme right upper corner being an outlier capable of changing the ordination, the same analysis was repeated without it. Nonetheless, the resulting ordination was similar to this one so we kept this site for the analysis (results not shown). All lichen traits chosen for this study seem to be mediating lichens response to the environmental gradients, as shown by the overlay of functional trait variables in the solution (**Figure 3.1.1**). The community weighted mean (CWM) of all lichen functional groups were well distributed along the first axis whereas on the second axis only fruticose species were associated (**Figure 3.1.1**). Species with an ecological preference for xeric habitats, high nutrients, higher solar radiation and basic pH substrate were associated to sites with N deposition from fertilizers from adjacent land uses (rice fields and others). Species that have ecological preferences for moister habitats, low nutrients, low solar radiation and acidic pH substrate were associated to sites with lower N deposition levels from fertilizers from adjacent land uses.

Table 3.1.2: Spearman correlations between the scores of the ordination of lichen communities' (NMS1 and 2), the environmental factors and the CMW of all lichen traits and respective functional groups. Significance of the correlation is indicated in superscript: * = p<0.05; ** = p<0.01; *** = p<0.001; "Ns" = non-significant.

Variable		**Description**	**Symbol**	**NMS 1**	**NMS 2**
Environmental Factor	Grazing Intensity	Grazing intensity recorded since 2007 until 2016	GI	Ns	Ns
	Years of Exclusion	Number of years without any cattle grazing	YE	Ns	Ns
	Distance to Road	Number of meters from every sampling site to the closest road	DR	Ns	Ns
	N 500m	Amount of fertilizer inputs from neighbour land uses located in a buffer around 500m of the sampling site	N500	Ns	Ns
	N 1500m	Amount of fertilizer inputs from neighbour land uses located in a buffer around 1500m of the sampling site each sampling site	N1500	0.69**	Ns
	Land surface temperature	Soil temperature	LST	Ns	Ns
Functional trait based	Growth form	Foliose broad lobes	Fob	-0.93***	Ns
		Foliose narrow lobes	Fon	0.97***	Ns
		Fruticose	Fr	-0.54*	-0.66**
	Reproduction type	Asexual	Asx	-0.92***	Ns
		Sexual	Sex	0.92***	Ns
	Eutrophication tolerance	Oligotrophic	Oligo	-0.74***	Ns
		Mesotrophic	Meso	-0.97***	Ns
		Nitrophytic	Nitro	0.99***	Ns
	pH	Sub-neutral	S-Neu	-0.97***	Ns
		Basic	Bas	0.97***	Ns
	Irradiation	Sun-exposed	Expo	-0.91***	Ns
		Very high direct solar irradiation	Direct	0.91***	Ns
	Aridity	Mesophytic	Mesop	-0.97***	Ns
		Xerophytic	Xerop	0.97***	Ns

Trait based diversity metrics showed significant correlations with N 1500m (**Table 3.1.1**). N 1500m was significantly correlated with all functional groups.

Regarding the trait growth form, foliose broad lobed and fruticose lichens functional groups were negatively correlated with N 1500m, while foliose narrow lobed lichens were positively correlated with it (**Table 3.1.1**). Reproduction type was correlated with N 1500m. Lichens with asexual reproduction were negatively correlated with N 1500m while the ones with sexual reproduction were positively correlated with it. As for the eutrophication tolerance trait, N 1500m showed negative correlations with oligotrophic and mesotrophic lichens, and positive correlations with nitrophytic ones. In the pH tolerance trait, again, N 1500m showed significant negative correlations with sub-neutral pH functional group and positive significant correlations with species with more tolerant to basic pH substrates. Within the ecological preferences for sun exposure trait, lichens with preference for sun exposure showed a negative response to N 1500m, while lichens with preference for shade exposure showed a positive response to them. Lastly, when analysing the aridity tolerance trait, we saw that mesophytic lichens were negatively affected by N 1500m while xerophytic lichens were positively affected (**Table 3.1.1**).

As seen above, all functional groups and the ordination scores of lichen communities were significantly correlated with the N1500 m environmental factor (**Table 3.1.2**). For all correlations with ρ value equal or superior to 0.2, we performed general linear models. From these, only those with significant P-value ($p<0.05$) are presented in **Table 3.1.3** (See **Table VII** in Appendix). Performance of the general linear models (**Table 3.1.3**) allowed us to identify the N 1500m as the most important factor, negatively affecting oligotrophic functional group (Oligotrophic: Estimate = -5.79E-06 ± 1.52E-06) and positively affecting the overall lichen community (NMS1: Estimate = 3.74E-05 ± 1.10E-05). Grazing intensity negatively affected fruticose functional group (Fruticose: Estimate = -3.95E-04 ± 1.47E-04). The best model was with the oligotrophic lichens and the N 1500m (Oligotrophic: AIC = 45.966).

Table 3.1.3: Summary of the generalized linear models examining the effects of environmental factors on axis 1 lichens' ordination scores and two functional groups. For more information regarding the environmental factors see **Table 2.3.1**.

	Effect	Estimate ± SE	F-value	P-value	AIC	adjR^2
NSM1	N 1500m	3.74E-05 ± 1.10E-05	3.407	3.36E-03	45.966	40.569
Oligotrophic	N 1500m	-5.79E-06 ± 1.52E-06	-3.809	1.40E-03	-29.21	46.051
Fruticose	Grazing intensity	-3.95E-04 ± 1.47E-04	-2.680	0.016	-26.579	29.701

The abundance of lichens of the oligotrophic functional group were shown to be the more appropriate metric to measure the effect of multiple farming activities in the *montado*. Therefore, we used this metric as a tool for the assessment of those effects. By using this better metric, we were able to build a map for the entire distribution of *montado* within the study area thus showing the impact of farming activities within the study area. Due to the fact that the most important impact source was from nearby intensive agriculture areas, this map shows (**Figure 3.1.2**), in red, the areas affected by the nitrogen from those agriculture areas.

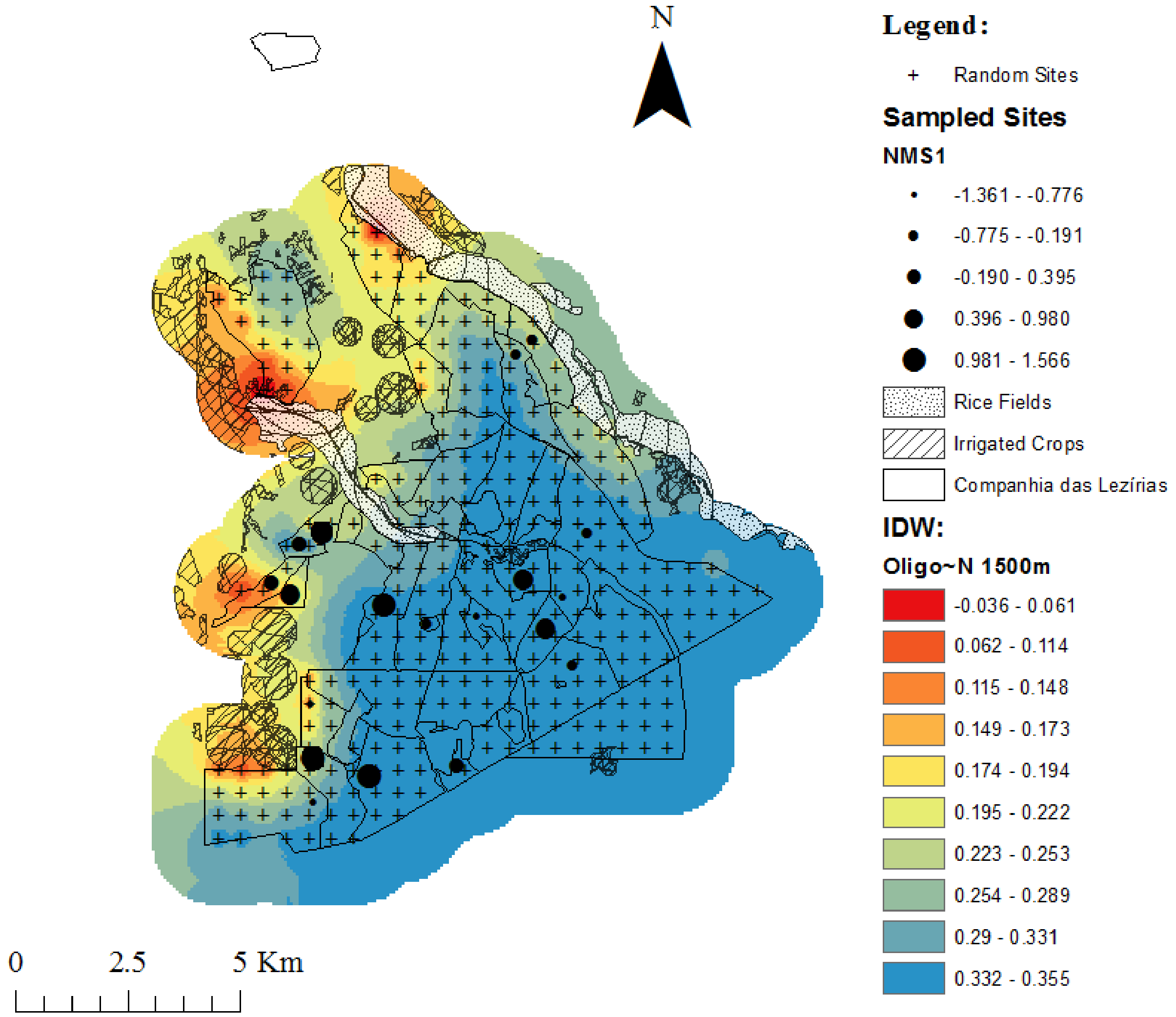

Figure 3.1.2: Spatial interpolation of the oligotrophic lichens CWM values calculated for the sampled sites and estimated for the 307 non-sampled sites. In this map, areas coloured in blue translate the highest oligotrophic abundance values, in yellow the medium values and in blue the lowest values. Black dots correspond to the sampled points, black crosses to the regularly spaced points, the white dotted areas the rice fields and the white stripped areas the watered temporary crops. Black lines correspond to the CL plots boundaries.

3.2. Beetles' diversity analyses:

In what concerns the taxonomic diversity, coprophagous beetle´s abundance showed no significant correlations with any environmental factor or land types tested (**Table 3.2.1**). On the other hand, coprophagous beetles' species richness (Nsp) showed significant correlations with the normalized difference moisture index from April (NDMI April), (**Table 3.2.1**).

Table 3.2.1: Spearman correlations between beetles taxonomic diversity, beetles community ordination axes scores (NMS1, NMS2 and NMS3), and beetle trait based diversity (Dung manipulation method, size class and wings presence) and the environmental factors. Significance of the correlation is indicated in superscript: * = p<0.05; ** = p<0.01; *** = p<0.001; "Ns" = non-significant. The codes of the variables are explained in **Table 2.2.2.1**. GI stands for grazing intensity, YE for years of exclusion, DR for distance to the road, N500 and N1500 for, respectively, N500 m and N1500 m, LST for land surface temperature, HS –Good, HS-Medium and HS-Bad for, respectively, habitat suitability – favorable land uses, habitat suitability – moderately favorable land uses and habitat suitability – unfavourable land uses, Soil Text, Soil Thick, Soil Pot and Soil Act for, respectively, soil texture, soil thickness, soil potential permeability and soil actual permeability and NDMI Apr and NDMI Jul for, respectively, NDMI April and NDMI July.

	Taxonomic based metrics		**Trait-based metrics**											
	Nsp	**Abundance**	**NMS1**	**NMS2**	**NMS3**	**Dwe**	**Roll**	**Tun**	**A**	**B**	**D**	**E**	**NW**	**W**
GI	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
YE	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
DR	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
N500	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
N1500	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
LST	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
HS-Good	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
HS-Medium	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
HS-Bad	Ns	Ns	Ns	0.48*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Soil Text	Ns	Ns	0.61**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Soil Thick	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Soil Pot	Ns	Ns	0.59**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Soil Act	Ns	Ns	0.56*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	-0.48*	Ns	Ns	Ns
NDMI Apr	0.54*	Ns	Ns	-0.51*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
NDMI Jul	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

The community analysis of beetles enabled to see the ordination of the sites according to beetles' species composition. The analysis suggested a three-dimensional solution. Most of the variation was explained by the first axis (48.2%), the second axis explained 21.7%, while the third explained 14.2% of the total variance (84.1%). The minimum stress of the solution was 8.8% and was lower than expected by chance (p = 0.02). **Figure 3.2.1** shows the joint plot where environmental and functional group variables were overlaid as vectors. Only vectors with significant correlations are shown to prevent overcrowding.

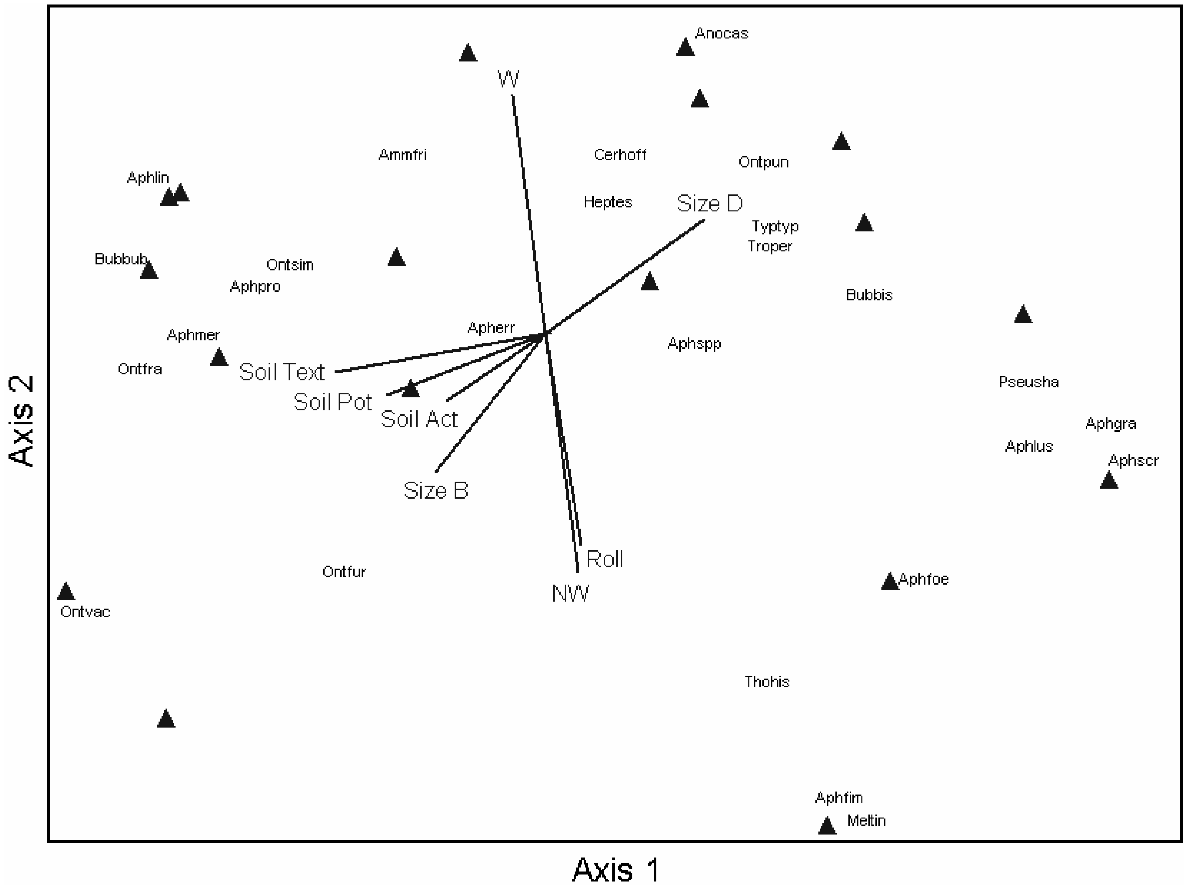

Figure 3.2.1: NMS joint plot showing the ordination of sampling sites (triangles) according to coprophagous beetles' communities. Vectors represent environmental factors and beetles functional groups. Environmental factors: Soil Pot, Soil Act and Soil Text stands for, respectively, for the potential permeability, actual permeability and the texture of the soil. Size B and D stands for, respectively, size classes between 0.475 cm to 0.95 cm and 1.426 cm to 1.9 cm. Roll are the rollers functional group. Lastly, W and NW stand for, respectively, winged and no winged functional groups. The three axes explained, respectively, 48.2%, 21.7% and 14.2% of the variance.

Some of the environmental factors studied showed significant correlations with the first (NMS1) and second (NMS2) axes scores of beetle's ordination (**Table 3.2.2**). None of the environmental factors showed any significant correlations with the third axis. Results suggest that the first axis seems to reflect a gradient in terms of soil properties (Soil actual permeability, Soil potential permeability and Soil texture), as seen by the significant correlations with soil texture, soil potential permeability and actual permeability. This means that the first axis from the beetles' ordination translates a gradient of soil texture and permeability, from thin to coarse soil particles and from highly to low permeable rankings. Regarding the second axis, habitat suitability – Bad and NDMI April were the two environmental factors to show significant, opposite correlations with it (**Table 3.2.2**). This means that this axis reflects a gradient of habitats with increasing bad habitat suitability for beetles, and, simultaneously, a gradient of increasingly moister vegetation (NDMI April).

The overlay of the vectors of the CWM functional groups on the ordination (**Figure 3.2.1**) shows that species with the second smallest size class were located in the side of the first axis corresponding to places with coarse soil particles and with higher potential and actual permeability rankings. Species with the second largest size class were located in the opposite side of the axis, corresponding to places with thinner soil particles, lower potential and actual soil permeability rankings. On the other hand, beetles with wings were located in one side of the second axis, corresponding to sites with worse habitat quality for beetle's presence. No winged and roller beetles were located in the opposite side of that axis, in places with higher vegetation moisture. Lastly, all functional groups from the dung manipulation method (dwellers. rollers and tunnelers) and from the wings (wings and no wings) traits showed significant correlations with the third axis. Nonetheless, none of the environmental factors studied were able to explain the gradient seen in beetles' communities.

Table 3.2.2: Spearman correlations between the scores of the ordination of beetles communities' (NMS1, 2 and 3) with the environmental factors and the CMW of all beetles traits and respective functional groups. Significance of the correlation is indicated in superscript: * = p<0.05; ** = p<0.01; *** = p<0.001; "Ns" = non-significant.

Variable		Description	Symbol	NMS1	NMS2	NMS3
Environmental Factor	Grazing Intensity	Grazing intensity recorded since 2007 until 2016	GI	Ns	Ns	Ns
	Years of Exclusion	Number of years without any cattle grazing	YE	Ns	Ns	Ns
	Distance to Road	Number of meters from every sampling site to the closest road	DR	Ns	Ns	Ns
	N 500m	Amount of fertilizer inputs from neighbour land uses located in a buffer around 500m of the sampling site	N500	Ns	Ns	Ns
	N 1500m	Amount of fertilizer inputs from neighbour land uses located in a buffer around 1500m of the sampling site each sampling site	N1500	Ns	Ns	Ns
	Habitat suitability – favorable land uses	Sum of all favorable land uses for coprophagous beetles communities in a 1500m buffer around each sampling site	HS - Good	Ns	Ns	Ns
	Habitat suitability – moderately favorable land uses	Sum of all moderately favorable land uses for coprophagous beetles communities in a 1500m buffer around each sampling site	HS-Medium	Ns	Ns	Ns
	Habitat suitability - unfavourable land uses	Sum of all unfavourable land uses for coprophagous beetles communities in a 1500m buffer around each sampling site	HS-Bad	Ns	0.48*	Ns
	Land surface temperature	Soil temperature	LST	Ns	Ns	Ns
	Soil Texture	Soil texture in a superficial layer of 30cm. Only focuses on the evaluation of the particulates with a diameter less than 2 mm	Soil Text	0.61**	Ns	Ns
	Soil Thickness	Effective soil thickness	Soil Thick	Ns	Ns	Ns

	Soil Potential Permeability	Water infiltration capacity of the soil, considering the influence of the geological substrate, soil and slope	Soil Pot	0.59**	Ns	Ns
	Soil Actual Permeability	Water infiltration capacity of the soil, considering the influence of the geological substrate, soil, slope and vegetation cover	Soil Act	0.56*	Ns	Ns
	NDMI April	Estimated levels of moisture in vegetation during spring season	NDMI Apr	Ns	-0.51*	Ns
	NDMI July	Estimated levels of moisture in vegetation during summer season	NDMI Jul	Ns	Ns	Ns
Functional trait based	Dwellers	Live inside or on top of the dung	Dwe	Ns	Ns	-0.75***
	Rollers	Build small balls of dung and then roll them to other places	Roll	Ns	Ns	0.49*
	Tunnelers	Dig tunnels below the dung, grabbing small amounts of it and placing them along the tunnel walls	Tun	Ns	Ns	0.59*
	[0-0,48]	Beetles with very small mean body size, from 0cm to 0,48cm	Size A	Ns	0.61**	Ns
	[0,49-0,95]	Beetles with small mean body size, from 0,49cm to 0,95cm	Size B	0.53*	-0.53*	Ns
	[1,43-1,9]	Beetles with large mean body size, from 1,43cm to 1,9cm	Size D	-0.58*	Ns	Ns
	[2-2,48]	Beetles with very large mean body size, from 2cm to 2,48cm	Size E	Ns	Ns	Ns
	No Wings	Absence of wings; Inability to fly	NW	Ns	-0.53*	0.58*
	Wings	Presence of wings; Ability to fly	W	Ns	0.53*	-0.58*

Trait based diversity showed some significant correlations with some environmental factors, namely with the CWM of beetles' functional groups belonging to dung manipulation and classes of size traits (**Table 3.2.1**). Regarding the dung manipulation trait, none of the functional groups showed significant correlations with any of the environmental factors tested. Concerning the size trait, the smaller and bigger mean beetle size classes showed no significant correlations with the environmental factors. Size B wasn´t correlated with any of environmental factors. Size D, in turn, showed significant positive correlations with soil pH and negative correlations with the soil actual permeability and the permanent pastures. The presence of wings trait was not significantly correlated with any of the environmental factors studied.

As seen above, the scores of beetles' community ordination and some functional groups were significantly correlated with one or two environmental factors (**Table 3.2.1**). For all correlations with ρ value equal or superior to 0.2, we performed general linear models. From these, only those with significant P-value ($p<0.05$) are presented in (**Table 3.2.3**) (See **Table VIII** in Appendix). Performance of the general linear models (**Table 3.2.3**) allowed us to identify several soil characteristics (Land surface temperature, soil thickness and soil actual permeability as the most important factors. LST and soil actual permeability negatively affected, respectively, rollers and Size

D functional groups (Rollers: Estimate = -0.040 ± 0.016) and (Size D: Estimate = -0.177 ± 0.060) while soil thickness and soil actual permeability positively affected, respectively the Size A and Size B functional groups (Size A: Estimate = 0.113 ± 0.045) and (Size B: Estimate = 0.190 ± 0.085). The best model was with the size D beetles and the soil actual permeability (Size D: AIC = 35.054).

Table 3.2.3: Summary of the generalized linear models, examining the effects of environmental factors on axis 1 scores from the beetles' ordination and several functional groups. For more information regarding the environmental factors see **Table 2.3.1**.

	Effect	Estimate ± SE	F-value	P-value	AIC	adjR^2
Rollers	LST	-0.040 ± 0.016	-2.477	0.025	-36.249	27.718
Size A	Soil Thickness	0.113 ± 0.045	2.524	0.023	-24.643	28.482
Size B	Soil actual permeability	0.190 ± 0.085	2.244	0.039	8.069	23.943
Size D	Soil actual permeability	-0.177 ± 0.060	-2.939	9.63E-03	-4.240	35.054

4. Discussion

Overall, we developed a tool to use epiphytic lichens and coprophagous beetles as ecological indicators to evaluate the diverse impacts that multiple farming activities have in air and soil compartments in a *montado* system. The primary driver of changes in lichen communities was associated with nitrogen deposition from fertilizers inputs by nearby agricultural fields. Additionally, we found that all lichen functional groups were suitable ecological indicators of these impacts. The grazing intensity, another activity taking place in *montado*, showed to impact in a negative way the fruticose lichens group, like previous works found (Stofer et al. 2006). Farming activities did not impact directly the beetles' diversity (taxonomic and functional). Instead, beetles were responding to factors associated with soil heterogeneity, showing that these ecological factors, eventually, masked any response to the farming activities. The main drivers for beetle's diversity were the soil features (soil texture, soil actual and soil potential permeability), the amount of surrounding habitat with low suitability for beetles and the vegetation moisture. This was evaluated based on expert analysis considering the vegetation structure of the *montado* being favourable or not to the beetle communities.

Gazing activities inside *montado* did not have a major effect on the community as only a minor effect was observed with fruticose lichens. Moreover, this effect was only noticeable in a site with very high cattle grazing intensity, where only lichens were sampled. In general, we conclude, regarding the effects of grazing, that its intensity is probably too low to drive changes in community structure of the selected ecological indicators.

This result greatly reinforces the classification of *montado* as a High Nature Value Farmland (HNVF), where agricultural practices are beneficial for the maintenance of the ecosystem balance. In montado areas, for example, it is assumed that low intensity and extensive grazing is not impacting the maintenance of the natural processes and services that these ecosystems may provide. This was confirmed in our work, even for lichens, which are one of the more sensitive groups to environmental changes, namely to nitrogen (Shibata et al., 2015). This is reinforced by the fact that only a single site, with high grazing intensity, has shown effects in lichens communities. Low to none impact level from the grazing activities can be due to two reasons: 1) grazing management is extensive, with low cattle densities; 2) cattle is, in general, not feed with extra food, except in a single location (the one with higher cattle density), and as a consequence do not receive extra nitrogen. This happens because the number of cattle heads is under the maximum capacity of pastures productivity, and consequently ammonia emissions are probably rather low, like it was observed by other authors in nearby locations (Daun & Santos, 2013; Pinho et al. 2012). Therefore, the amount of ammonia volatized from cattle dung and then deposited locally is not contributing to increase the local ammonia concentrations above the critical levels for lichens (P. Pinho, Theobald, et al. 2012), not having an impact in the epiphytic lichens and coprophagous beetles' communities.

4.1. Air compartment

The study of epiphytic lichen communities allowed us to identify the main driver responsible for shifts in their communities in a High Nature Value Farmland (HNVF): nitrogen inputs from fertilization in nearby agricultural crops. This environmental factor was highly associated to all functional and with lichens abundance. Secondary to this main shift in lichens communities, we found a response to grazing intensity. As said above, contrarily to what was initially expected, cattle grazing was not the most pressing impact on lichens. This may be due to the reason that the amount of ammonia volatized and then deposited is lower than the critical levels for lichens (Pinho et al. 2012), not causing major impacts in their communities.

The analysis of lichen traits allowed us to see which traits mediate these shifts in lichen communities. A closer look to lichen functional trait diversity showed us that functional groups with different tolerance to eutrophication, pH, irradiation and aridity levels and also growth form and main reproduction type responded in varied ways to the multiple farming activities, allowing a better understanding of their impacts in High Nature Value Farmland (HNVF). As expected, oligotrophic and mesotrophic lichens, more sensitive to higher eutrophication levels, responded negatively to the nitrogen deposition, while nitrophytic lichens had a positive response to it, going along with a vast number of other studies findings (Jovan & Mccune, 2006; Pinho et al. 2008; Pinho et al. 2009, 2011). Lichens with preference for more alkaline substrates responded positively to nitrogen deposition. This can be due to the fact that nitrogen raises bark pH (Van Herk et al. 2003) and to the effect of dust formation (either from the wind or by cattle grazing) that also raises the cork oak bark pH (Giordani & Malaspina, 2017; Pinho et al. 2008; VanHerk, 2001). Likewise, foliose with narrow lobes showed to be more tolerant to nitrogen deposition, in line with their general classification as nitrophytic species (Nimis, 2016). On the other hand, foliose broad lobed lichens had the opposite response. This is in agreement with (Nimis, 2016). Fruticose species, special Usnea sp., were associated with less nitrogen deposition. These species are usually regarded as more sensitive to eutrophication. In fact, this was the only functional group that responded to grazing intensity. Their three dimensional growth form, adapted to maximize particles and water absorption makes them more sensitive to N deposition (Matos et al. 2015). The main type of reproduction in lichens may be determined by the environmental stress levels that surround their communities (Martínez et al. 2012). The analysis of this trait revealed that sexual reproduction was positively correlated with higher nitrogen deposition areas, thus with more environmental stress, pointing out the fact that lichens communities, in areas with high nitrogen levels, tend to be dominated by species who use sexual reproduction during stress times to increase the genetic poll. Functional groups from the irradiation and the aridity traits tend to have an integrated response reflecting microclimate and vegetation structure (Gauslaa & McEvoy, 2005).

Lichens species richness was negatively affected by nitrogen deposition from fertilizer inputs from neighbouring land uses within 500 m from the sampling sites and the abundance from land uses within 1500 m from the sampling sites. This is in line with previous studies showing that lichens are susceptible to air pollution caused by nitrogen compounds (Bal et al. 2012; Luisa Frati et al. 2008; Pinho et al. 2012; Van Herk et al. 2003). In addition, these results are consistent with other works showing that nitrogen compounds can be deposited at such distances from the source (Hauck & Lkhagvadorj, 2013; Pinho et al. 2011; Van Herk et al. 2003). Though we were able to find a correlation between taxonomic metrics and N deposition, this metric was not as good as the trait-based and community metrics to understand how each farming activity is impacting the communities. Previous works under similar ecosystems have already found that this metrics is not the most suitable to track the effects of grazing and farming activities (Pinho et al. 2012).

4.2. Soil compartment

The study of the coprophagous beetle's communities allowed us to see that this ecological indicator is associated with soil characteristics, bad habitat suitability and the NDMI. Although this was not the first time that a study confirmed a relationship between soil characteristics and beetles communities assembly (Allsopp, Klein, & McCoy, 1992; Davis, 1996; Ishitani, Kotze, & Niemelä, 2003), it´s still important to highlight this result. In this case further use of beetles should have in consideration the soil type at high spatial resolution before deciding the sampling design, since it is a confounding factor that we need to have in consideration to use beetles as good ecological indicators. The vegetation moisture and the amount of nearby habitat with less suitability to support beetles communities were the secondary sources of variability in beetles' communities, thus we were able to find an indicator of the NDMI April and habitat suitability based on the second axis from the beetles NMS. This corroborates previous works by Giuseppe et al. (2007) and Horgan (2007). Contrarily to what was initially expected, cattle grazing did not impact beetles communities. We expected this to be the main driver, as the presence of more dung should either positively influence their communities as more food is available and more places to nest on (Abot et al. 2012; Buse et al. 2015; Lobo et al. 2006), or negatively by soil compaction or mechanic abrasion from the grazing activity itself. The fact that grazing intensity had a significant impact only in lichen communities is due to the fact that only the lichen community was sampled in an extra place with very high cattle grazing intensity. This was not possible to do with beetle communities due to time constraints. Futures studies should also contemplate sites with even higher intensities. Nonetheless, as mentioned for lichens, the absence of response to grazing may be due to the low grazing intensity present in the study area.

The analysis of coprophagous beetles' traits allowed us to see which traits mediate these shifts in beetles' communities. Results from the GLMs allowed us to identify the relationship between the intermediary beetles' sizes and the soil texture (soil particles size). Some literature also highlights the relationship between beetles body size and the soil texture (Allsopp et al. 1992; Stapp, 2012). In fact, studies suggest that species with bigger sizes preferentially occur in sandy soils (larger soil particles) while smaller species tend to be also found in clayey soils (smaller soil particles) (Davis, 1996; Sowig, 1995). Soil texture is also highly connected with soil permeability, as larger soil particles have more space between them enhancing water infiltration rates (Arya & Paris, 1981; Elhakim, 2016). Therefore, we would expect to see a positive association between our captured larger species and soils with larger particles. Instead, our results suggest an opposite response where smaller species are actually the ones to be positively associated with larger soil particles and with more permeable soils. This may be related to the fact that despite data referring that there are three types of particles sizes in the study area (thin, medium and coarse), probably there aren´t very sandy soils or very clay soils, thus not affecting beetles.

Species richness was only related with the normalized difference moisture index from April (NDMI), which translates the levels of moisture in the vegetation. Although beetles aren´t very dependent on the vegetation characteristics, they are dependent on soil moisture to dig tunnels, store food and breed their offspring (Stapp, 2012). Therefore, it is possible that this index is also translating moisture levels (Fatemeh et al. 2015), thus we can expect that there will be more species in places with higher NDMI. Beetles abundance was not correlated with any of the studied environmental drivers as was also found in a study in Central Spain where 16 communities were sampled ((Lobo el at. 2006)).

Beetles sampling period was performed during early spring (due to calendar restrictions), before what is usually the peak seasonal activity for this group which is during late spring and summer (Fazekas et al. 1997; Rainio & Niemela, 2003; Yu et al. 2006). This may have had repercussions in the amount of specimens caught and consequently made it harder to identify the impacts of the multiple farming activities.

4.3. Building a tool for management

Regarding **figure 3.1.2**, all of the *montado* areas within less than 1500 m from the rice fields and the irrigated crops are probably impacted by the nitrogen compounds from the fertilizes inputs in such intensive agriculture areas. Beyond 1500 m from those areas, the effects are no longer predicted, and we can consider that the *montado* in those areas is representative of the background levels. The impacted areas, visible in this map, (**Figure 3.1.2**) only take in consideration the effect from the nitrogen compounds, thus being independent from the grazing intensity or grazing exclusion (that had no effect on the selected ecological indicator).

After identifying the areas impacted by nitrogen deposition from nearby agricultural areas, we wanted to understand if the deposition levels were above the critical levels (CLe) for NH_3 concentration. CLe translate "the concentration above which direct adverse effects on receptors may occur, based on present knowledge" (Posthumus, 1988). Pinho et al. (2012) estimated the atmospheric ammonia critical levels for a montado ecosystem located nearby our study area to be below 1.9µg/m^3. This CLe was estimated based on the NH_3 concentration levels above which an alteration in the proportion of most sensitive species, oligotrophic, was observed when compared to a control area. Because our study area is very similar, we applied their equation relating CWM of oligotrophic species with NH_3 to estimate the NH_3 values for our study area. This was was done using the CWM of oligotrophic values estimated for the whole area using the model of N deposition (values used to build the map in **figure 3.1.2**). The map in **figure 4.3.1** shows the NH_3 values estimated for the study area. In this figure, blue and light green areas correspond to the areas were the NH_3 concentrations are lower than the CLe in by Pinho et al. (2012), i.e lower than 1.9µg/m^3. These areas are the ones who are more distant from the irrigated crops and rice fields where the fertilizers inputs, rich in nitrogen compounds, take place. Areas closer to the irrigated crops and rice fields are the ones where the CLe values, for this type of ecosystems are overtaken. Nonetheless, it is important to highlight that, if we take into consideration the CLe legal value, which is 1µg/m^3 (Cape et al., 2009), the entire study area is above it. This can be due to the fact that the study area is located close to Lisbon, which contains large industrial and urban areas, contributing to higher levels of nitrogen deposition.

For conservation policies, areas up to 1500 m could be considered as buffer areas, protecting the areas further away. Because nitrogen deposition is higher in forested areas (Dore et al. 2007), buffer areas should be forested, to optimize the protection buffer effect. In land-sparing conservation policies, any land spared for conservation policies must also be located at more than 1500 m from intensive agriculture. It is important to note that we selected the distance of 1500 m as having the more impact in lichens because it resulted in the more significant correlation. We did not tested at higher distances because ammonia is expected to be dispersed up to 1000 m from source (Dore et al. 2007). Thus this distance can be interpreted as conservative, ensuring the protection of ecosystems. It is also important to note that because we used epiphytic lichens, which are among the organisms more sensitive to atmospheric nitrogen within the *montado*, map from **figure 3.1.2** shows the first effects of nitrogen in the *montado*. Because these semi-natural ecosystems, with high biodiversity and services provided, depend on the low intensity of the agricultural activities there performed, it is vital to apply the thresholds in order to set strict limits to farming activities intensification. Thresholds for these kinds of ecosystems have already been defined, both in legislation and on previous studies. Therefore, we can use this tool to apply them in *montado* areas.

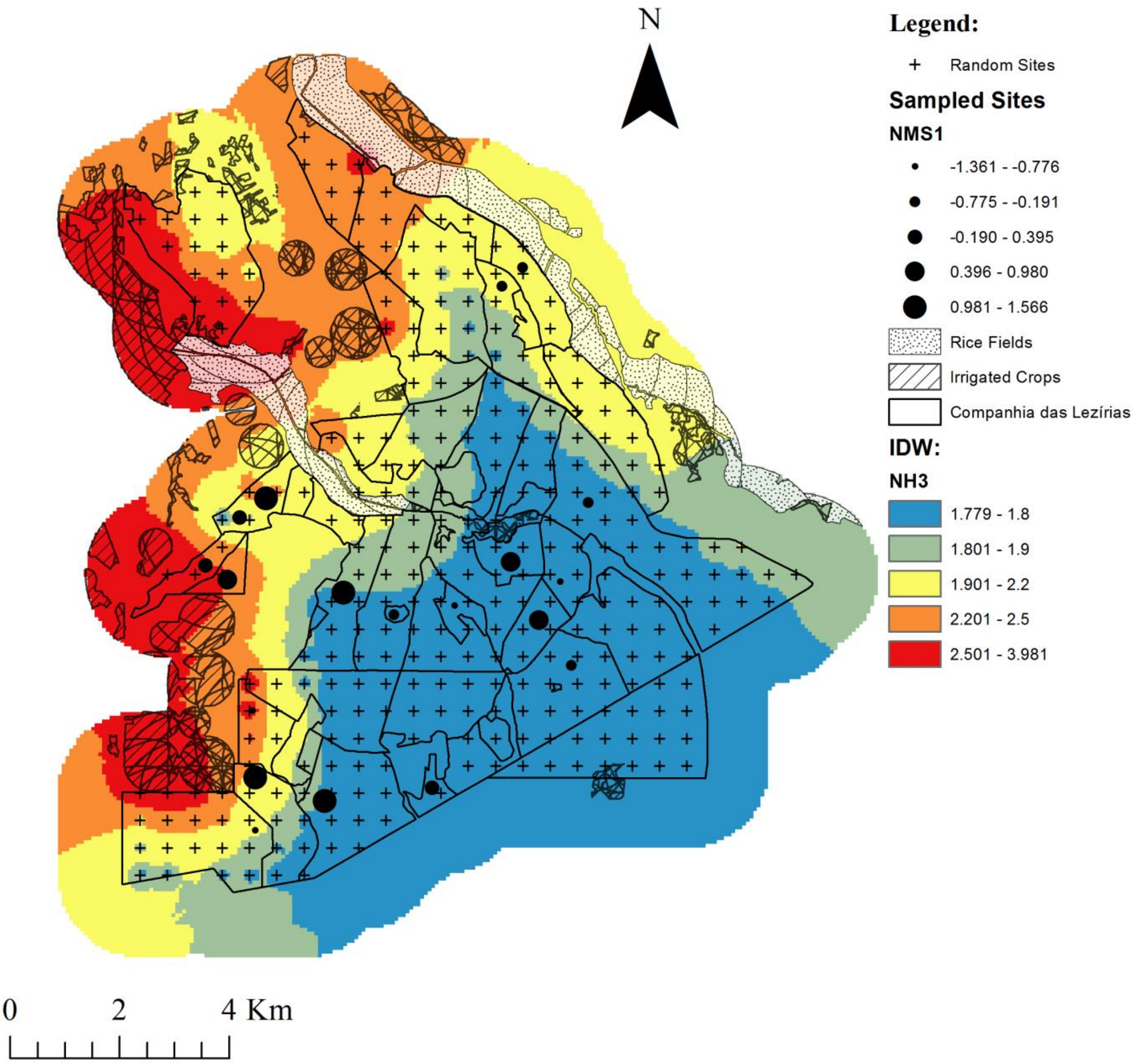

Figure 4.3.1: Spatial interpolation of the NH_3 values estimated for the 307 non-sampled sites. In this map, areas coloured in blue and light green translate the areas with NH_3 concentrations lower than the critical levels (1.9µg/m^3) while areas coloured in yellow, orange and red translate the areas with NH_3 concentrations higher than the critical levels (1.9µg/m^3). Black dots correspond to the sampled points, black crosses to the regularly spaced points, the white dotted areas the rice fields and the white stripped areas the watered temporary crops. Black lines correspond to the CL plots boundaries.

5. Conclusions

Our aim was to build a management tool to understand the impacts of multiple farming activities in High Nature Value montado areas. To fulfil that goal, we used epiphytic lichens and coprophagous beetles as ecological indicators of a series of multiple farming activities like cattle grazing and crops production in air and soil compartments, respectively. Lichens revealed to be good ecological indicators to access impacts caused by nitrogen compounds in nearby farming crops as they responded to the impact from nitrogen compounds deposition. Thus, we recommend the use of lichens in fertilization impact studies. Study of the coprophagous beetles communities' didn´t allow us to determine the impact of any of the farming activities present in the study area. However, if further studies take in consideration the soil characteristic of the sampled sites, beetles may reveal to be good ecological indicators of multiple farming activities. We also highlight the fact that trait based metrics are important tools to identify not only the impacts but also their source.

Lastly we showed that, at low intensity levels, grazing can be an environmentally friendly farming activity.

The Portuguese montado is a profitable land-use, especially because of cork production. However, without the right management strategies implemented, it can start to degrade itself to a point of no return. Climate changes, land uses intensification and increased anthropogenic pressures will only aggravate this problem. Thus, we hope that in the future, tools like the one we provide in this study can be actively used in management of the montado farming activities.

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7. Appendix

Appendix I – Table with the measured coprophagous beetles body size classes and correspondent classes' number and code:

Body size classes	Classes	Code
[0.00 – 0.47]	1	A
]0.47 – 0.95]	2	B
]0.95 – 1.43]	3	C
]1.43 – 1.90]	4	D
]1.90 – 2.48]	5	E

Appendix II – Table with soil characteristics: soil texture, thickness, potential permeability and actual permeability and correspondent classes´ numbers:

Soil Texture	Soil Thickness	Soil Potential Permeability	Soil Actual Permeability	Soil Class
No Data	No Data	Water body	Water body	0
Thin	<25	Low	Low	1
Medium	25 - 50	Low to Moderate	Low to Moderate	2
Coarse	50 - 75	Moderate	Moderate	3
Non	75 - 100	Moderate to High	Moderate to High	4
Non	>100	High	High	5

Appendix III – Table with all epiphytic lichens species collected and identified, and trait classification into respective functional groups. - (Main Photobiont; Growth Form; Reproduction Type; Eutrophication; pH; Irradiation; Aridity).

Species	Species code	Main Photo biont	Growth form	Reprod uction type	Eutrophicati on	pH	Irradiati on	Arid ity
Candelaria concolor	Cancon	Gr	Fon	As	Nitro	4	5	4
Evernia prunastri	Evepru	Gr	Fr	As	Meso	3	5	3
Flavoparmelia caperata	Flacap	Gr	Fon	As	Meso	3	4	3
Hyperphyscia adglutinata	Hypadg	Gr	Fon	As	Nitro	5	5	4
Melanelixia subaurifera	Melsub	Gr	Fon	As	Meso	3	4	3
Parmelia sulcata	Parsul	Gr	Fob	As	Meso	3	5	3
Parmelina tiliacea	Partil	Gr	Fon	As	Meso	2	4	3
Parmotrema hypoleucinum	Parhyp	Gr	Fon	As	Oli	3	5	2
Parmotrema perlatum	Parper	Gr	Fon	As	Oli	2	4	3

Species	Species code	Main Photo biont	Growth form	Reproduction type	Eutrophication	pH	Irradiation	Aridity
Phaeophyscia orbicularis	Phaorb	Gr	Fon	As	Nitro	5	5	4
Physcia adscendens	Phyads	Gr	Fon	As	Nitro	5	5	4
Physcia dubia	Phydub	Gr	Fon	As	Nitro	4	5	4
Physcia tenella	Phyten	Gr	Fon	As	Nitro	4	5	4
Physcia tribacioides	Phytri	Gr	Fon	As	Meso	3	5	2
Punctelia borreri	Punbor	Gr	Fon	As	Meso	3	4	3
Ramalina calicaris	Ramcal	Gr	Fr	S	Oli	2	4	2
Ramalina canariensis	Ramcan	Gr	Fr	As	Nitro	3	5	2
Ramalina farinacea	Ramfar	Gr	Fr	As	Oli	3	5	2
Ramalina fastigiata	Ramfas	Gr	Fr	S	Meso	3	5	3
Ramalina lacera	Ramlac	Gr	Fr	As	Meso	3	5	2
Ramalina subgeniculata	Ramsub	Gr	Fr	S	Oli	2	4	2
Usnea ceratina	Usncer	Gr	Frf	As	Oli	2	5	2
Usnea esperantiana	Usnesp	Gr	Frf	As	Oli	2	5	2
Usnea glabrescens	Usngla	Gr	Frf	As	Oli	2	5	2
Usnea hirta	Usnhir	Gr	Frf	As	Oli	2	5	3
Usnea rubicunda	Usnrub	Gr	Frf	As	Oli	2	4	2
Xanthoria parietina	Xanpar	Gr	Fon	S	Nitro	4	5	4

Appendix IV – Table with all coprophagous beetles species collected and identified, with trait classification and respective functional groups.– (Dung Manipulation Method, Wings Presence, Mean Size; Size Class)

Species	Species code	Dung manipulation Method	Wings Presence	Mean Size	Size Class
Ammoecius frigidus	Ammfri	Dweller	Yes	0.53	B
Anomius castaneus	Anocas	Dweller	Yes	0.62	B
Aphodius erraticus	Apherr	Dweller	Yes	0.56	B
Aphodius fimetarius	Aphfim	Dweller	Yes	0.65	B
Aphodius foetidus	Aphfoe	Dweller	Yes	0.52	B
Aphodius lusitanicus	Aphlus	Dweller	Yes	0.48	B
Aphodius granarius	Aphgra	Dweller	Yes	0.50	B
Aphodius lineolatus	Aphlin	Dweller	Yes	0.54	B
Aphodius merdarius	Aphmer	Dweller	Yes	0.53	B
Aphodius prodomus	Aphpro	Dweller	Yes	0.56	B
Aphodius scrutator	Aphscr	Dweller	Yes	0.95	B
Aphodius sp.	Aphspp	Dweller	Yes	0.65	B
Bubas bison	Bubbis	Tunneler	Yes	1.66	D
Bubas bubalus	Bubbub	Tunneler	Yes	1.67	D
Ceratophyus hoffmannseggi	Cerhoff	Rollers	Yes	2.25	E
Pseudacrossus sharpi	Pseusha	Dweller	Yes	0.57	B
Heptaulacus testudinarius	Heptes	Dweller	Yes	0.35	A
Melinopterus tingens	Meltin	Dweller	Yes	0.70	B
Onthophagus fracticornis	Ontfra	Tunneler	Yes	0.71	B
Onthophagus furcatus	Ontfur	Tunneler	Yes	0.63	B
Onthophagus punctatus	Ontpun	Tunneler	Yes	0.62	B
Onthophagus similis	Ontsim	Tunneler	Yes	0.74	B
Onthophagus vacca	Ontvac	Tunneler	Yes	0.73	B
Thorectes hispanus	Thohis	Rollers	No	0.63	B
Trox perlatus hispanicus	Troper	Tunneler	Yes	0.94	B
Typhaeus typhoeus	Typtyp	Tunneler	Yes	1.79	D

Appendix V - Spearman correlations between environmental factors use for lichen database. Significance of the correlations is indicated in superscript: * = p<0.05; ** = p<0.01; *** = p<0.001; "Ns" = non-significant. The codes of the variables are explained in **Table 2.2.1.1**. GI stands for grazing intensity, YE for years of exclusion, DR for distance to the road, N500 and N1500 for, respectively, N 500m and N 1500m and LST for land surface temperature.

	GI	**YE**	**Dr**	**N500**	**N1500**
GI					
YE	-0.88***				
DR	Ns	Ns			
N500	Ns	Ns	Ns		
N1500	Ns	Ns	Ns	0.47*	
LST	Ns	Ns	Ns	Ns	Ns

Appendix VI - Spearman correlations between environmental factors used for coprophagous beetles database. Significance of the correlation is indicated in superscript: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; "Ns" = non-significant. The codes of the variables are explained in **Table 2.2.2.1**. GI stands for grazing intensity, YE for years of exclusion, DR for distance to the road, N500 and N1500 for, respectively, N500 m and N1500 m, LST for land surface temperature, HS –Good, HS-Medium and HS-Bad for, respectively, habitat suitability – favorable land uses, habitat suitability – moderately favorable land uses and habitat suitability – unfavourable land uses, Soil Text, Soil Thick, Soil Pot and Soil Act for, respectively, soil texture, soil thickness, soil potential permeability and soil actual permeability and NDMI Apr and NDMI Jul for, respectively, NDMI April and NDMI July.

	GI	YE	DR	N500	N1500	LST	HS-Good	HS-Medium	HS-Bad	Soil Text	Soil Thick	Soil Pot	Soil Act	NDMI Apr
GI														
YE	-0.87***													
DR	Ns	Ns												
N500	Ns	Ns	- Ns											
N1500	Ns	Ns	Ns	0.50*										
LST	Ns	Ns	Ns	Ns	Ns									
HS-Good	Ns	Ns	Ns	Ns	-0.89***	Ns								
HS-Medium	Ns	Ns	Ns	Ns	0.79***	Ns	-0.89***							
HS-Bad	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns						
Soil Text	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns					
Soil Thick	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns				
Soil Pot	Ns	0.47*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	0.81***	Ns			
Soil Act	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	0.99***	Ns	0.80***		
NDMI Apr	Ns	Ns	0.47*	Ns	Ns	Ns	Ns	Ns	-0.50*	Ns	Ns	Ns	Ns	
NDMI Jul	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	0.48*

Appendix VII: Generalized linear models examining the effects of environmental factors on the two axes of lichens' ordination scores and functional groups. For more information regarding the environmental factors see **Table 2.3.1**. For more information regarding the functional groups see **Table 2.2.1.1**.

		Estimate	STD_Error	F_Value	P_Value	Aic
Fob	N1500	0.000	0.000	-2.734	0.014	-2.529
Fon	N500	0.000	0.000	1.615	0.125	11.391
	N1500	0.000	0.000	3.277	0.004	4.798
	(Intercept)	0.190	0.075	2.541	0.022	6.327
	N500	0.000	0.000	0.633	0.535	
	N1500	0.000	0.000	2.684	0.016	
Fr	GI	0.000	0.000	-2.680	0.016	-26.579
	YE	0.006	0.005	1.304	0.210	-21.696
	N1500	0.000	0.000	-2.226	0.040	-24.744
	(Intercept)	0.256	0.053	4.866	0.000	-24.580
	GI	0.000	0.000	-2.165	0.046	
	YE	0.000	0.005	0.019	0.985	
	(Intercept)	0.292	0.031	9.313	0.000	-29.305
	GI	0.000	0.000	-2.569	0.021	
	N1500	0.000	0.000	-2.126	0.050	
	(Intercept)	0.223	0.042	5.295	0.000	-25.161
	YE	0.007	0.004	1.473	0.160	
	N1500	0.000	0.000	-2.309	0.035	
Asx	N500	0.000	0.000	-2.147	0.047	-7.883
	N1500	0.000	0.000	-2.683	0.016	-10.032
	(Intercept)	0.855	0.049	17.575	0.000	-10.001
	N500	0.000	0.000	-1.322	0.205	
	N1500	0.000	0.000	-1.968	0.067	
Oligo	DR	0.000	0.000	-0.679	0.506	-17.993
	N500	0.000	0.000	-1.585	0.131	-20.104
	N1500	0.000	0.000	-3.809	0.001	-29.210
	LST	0.036	0.026	1.354	0.193	-19.431
	(Intercept)	0.350	0.066	5.290	0.000	-18.844
	DR	0.000	0.000	-0.797	0.437	
	N500	0.000	0.000	-1.609	0.127	
	(Intercept)	0.349	0.052	6.719	0.000	-27.242
	DR	0.000	0.000	0.164	0.872	
	N1500	0.000	0.000	-3.595	0.002	
	(Intercept)	-0.802	0.980	-0.818	0.425	-17.507
	DR	0.000	0.000	-0.253	0.804	
	LST	0.033	0.029	1.152	0.266	
	(Intercept)	0.357	0.031	11.620	0.000	-27.504
	N500	0.000	0.000	-0.500	0.624	
	N1500	0.000	0.000	-3.200	0.006	
	(Intercept)	-0.569	0.901	-0.632	0.537	-19.188
	N500	0.000	0.000	-1.245	0.231	
	LST	0.026	0.027	0.969	0.347	

		Estimate	STD_Error	F_Value	P_Value	Aic
	(Intercept)	-0.394	0.687	-0.573	0.575	-28.574
	N1500	0.000	0.000	-3.572	0.003	
	LST	0.022	0.021	1.091	0.291	
Meso	N1500	0.000	0.000	-2.483	0.024	-10.318
Nitro	N500	0.000	0.000	1.557	0.138	9.526
	N1500	0.000	0.000	3.490	0.003	1.792
	(Intercept)	0.202	0.069	2.913	0.010	3.467
	N500	0.000	0.000	0.525	0.607	
	N1500	0.000	0.000	2.907	0.010	
S-Neu	N1500	0.000	0.000	-3.552	0.002	2.000
	GI	0.000	0.000	-1.509	0.150	-0.617
	N1500	0.000	0.000	-2.207	0.041	-3.016
	(Intercept)	0.527	0.063	8.410	0.000	-2.920
	GI	0.000	0.000	-1.298	0.213	
	N1500	0.000	0.000	-2.016	0.061	
Mesop	N1500	0.000	0.000	-3.552	0.002	2.000
NMS 1	N500	0.001	0.000	1.697	0.108	52.880
	N1500	0.000	0.000	3.407	0.003	45.966
	(Intercept)	-0.477	0.220	-2.164	0.046	47.389
	N500	0.000	0.000	0.702	0.493	
	N1500	0.000	0.000	2.781	0.013	
NMS 2	GI	0.002	0.000	3.614	0.002	17.804

Appendix VIII: Generalized linear models examining the effects of environmental factors on the three axes of beetles' ordination scores and functional groups. For more information regarding the environmental factors see **Table 2.3.1**. For more information regarding the functional groups see **Table 2.2.2.1**.

		Estimate	STD Error	F Value	P Value	Aic
Dwe	Soi Act	0.094	0.074	1.270	0.222	3.053
	DR	0.000	0.001	0.657	0.520	4.301
	Soil Text	0.045	0.069	0.647	0.527	4.316
	N1500	0.000	0.000	0.432	0.672	4.572
	intercept	0.096	0.358	0.269	0.791	4.790
	Soil Act	0.088	0.077	1.146	0.270	
	DR	0.000	0.001	0.470	0.645	
	intercept	-0.032	0.413	-0.076	0.940	4.456
	Soil Act	0.176	0.137	1.278	0.221	
	Soil Text	-0.089	0.125	-0.711	0.488	
	intercept	0.124	0.355	0.349	0.732	4.951
	Soil Act	0.091	0.077	1.189	0.253	
	N1500	0.000	0.000	0.291	0.775	
	intercept	0.396	0.207	1.911	0.075	5.968
	DR	0.000	0.001	0.541	0.596	
	Soil Text	0.038	0.072	0.530	0.604	
	intercept	0.479	0.134	3.581	0.003	6.250

		Estimate	STD Error	F Value	P Value	Aic
	DR	0.000	0.001	0.521	0.610	
	N1500	0.000	0.000	0.207	0.839	
	intercept	0.421	0.194	2.170	0.047	6.078
	Soil Text	0.046	0.071	0.646	0.528	
	N1500	0.000	0.000	0.446	0.662	
Roll	Soi Pot	0.031	0.023	1.357	0.194	-32.367
	YE	0.007	0.003	2.178	0.045	-35.082
	HS-Medium	0.161	0.125	1.283	0.218	-32.169
	Soi Act	0.023	0.029	0.794	0.439	-31.103
	GI	-0.001	0.000	-2.055	0.057	-34.624
	DR	0.000	0.000	-0.132	0.897	-30.426
	LST	-0.040	0.016	-2.477	0.025	-36.249
	intercept	-0.037	0.099	-0.369	0.717	-33.213
	Soil Pot	0.009	0.026	0.332	0.745	
	YE	0.007	0.004	1.603	0.130	
	intercept	-0.088	0.099	-0.885	0.390	-31.200
	Soil Pot	0.023	0.025	0.940	0.362	
	HS-medium	0.114	0.135	0.843	0.412	
	intercept	-0.035	0.133	-0.263	0.796	-30.797
	Soil Pot	0.053	0.044	1.217	0.243	
	Soil Act	-0.032	0.053	-0.602	0.556	
	intercept	-0.046	0.098	-0.464	0.649	-33.002
	Soil Pot	0.014	0.024	0.564	0.581	
	GI	-0.001	0.000	-1.538	0.145	
	intercept	-0.078	0.105	-0.745	0.468	-30.497
	Soil Pot	0.032	0.024	1.352	0.196	
	DR	0.000	0.000	-0.330	0.746	
	intercept	1.158	0.562	2.060	0.057	-35.578
	Soil Pot	0.022	0.021	1.072	0.301	
	LST	-0.036	0.016	-2.244	0.040	
	intercept	-0.023	0.040	-0.565	0.580	-33.579
	YE	0.007	0.004	1.769	0.097	.
	HS-medium	0.082	0.126	0.648	0.527	
	intercept	-0.011	0.126	-0.089	0.930	-33.085
	YE	0.007	0.004	1.927	0.073	.
	Soil Act	0.001	0.029	0.050	0.961	
	intercept	-0.008	0.036	-0.228	0.823	-33.109
	YE	0.010	0.015	0.640	0.532	
	GI	0.000	0.001	0.150	0.883	
	intercept	0.013	0.047	0.272	0.789	-33.370
	YE	0.008	0.004	2.177	0.046	
	DR	0.000	0.000	-0.492	0.630	
	intercept	1.084	0.524	2.070	0.056	-37.652
	YE	0.006	0.003	1.767	0.098	
	LST	-0.032	0.016	-2.082	0.055	

		Estimate	STD Error	F Value	P Value	Aic
	intercept	-0.042	0.135	-0.310	0.761	-30.279
	HS-medium	0.143	0.142	1.007	0.330	
	Soil Act	0.010	0.031	0.304	0.765	
	intercept	-0.017	0.039	-0.442	0.665	-33.474
	HS-medium	0.104	0.123	0.851	0.408	
	GI	-0.001	0.000	-1.739	0.103	
	intercept	0.012	0.056	0.215	0.833	-30.363
	HS-medium	0.172	0.132	1.305	0.211	
	DR	0.000	0.000	-0.404	0.692	
	intercept	1.251	0.534	2.342	0.033	-35.824
	HS-medium	0.131	0.112	1.171	0.260	
	LST	-0.038	0.016	-2.353	0.033	
	intercept	-0.026	0.126	-0.204	0.841	-32.713
	Soil Act	0.008	0.028	0.272	0.789	
	GI	-0.001	0.000	-1.825	0.088	
	intercept	-0.056	0.139	-0.404	0.692	-29.183
	Soil Act	0.024	0.030	0.802	0.435	
	DR	0.000	0.000	-0.259	0.800	
	intercept	1.247	0.558	2.233	0.041	
	Soil Act	0.019	0.025	0.769	0.454	
	LST	-0.039	0.016	-2.398	0.030	
	intercept	0.025	0.047	0.539	0.598	-32.866
	GI	-0.001	0.000	-2.048	0.058	
	DR	0.000	0.000	-0.450	0.659	
	intercept	1.094	0.537	2.036	0.060	-36.966
	GI	0.000	0.000	-1.563	0.139	
	LST	-0.032	0.016	-2.023	0.061	
	intercept	1.372	0.552	2.488	0.025	-34.310
	DR	0.000	0.000	-0.226	0.824	
	LST	-0.040	0.017	-2.408	0.029	
Tun	HS-Good	0.388	0.305	1.272	0.221	0.789
	N1500	0.000	0.000	-0.588	0.565	2.139
	N500	0.000	0.000	-1.303	0.211	0.708
	DR	0.000	0.001	-0.646	0.527	2.061
	Soi Text	-0.065	0.064	-1.022	0.322	1.387
	Soi Act	-0.116	0.067	-1.746	0.100	-0.616
	NDMI Jul	0.553	0.508	1.089	0.293	1.239
	(Intercept)	0.020	0.354	0.058	0.955	2.577
	Hs-Good	0.525	0.450	1.166	0.262	
	N1500	0.000	0.000	0.422	0.679	
	(Intercept)	0.238	0.246	0.968	0.348	1.943
	Hs-Good	0.272	0.337	0.807	0.432	
	N500	0.000	0.000	-0.850	0.409	
	(Intercept)	0.208	0.250	0.829	0.420	2.399
	Hs-Good	0.376	0.313	1.204	0.247	

		Estimate	STD Error	F Value	P Value	Aic
	DR	0.000	0.001	-0.573	0.575	
	(Intercept)	0.301	0.290	1.036	0.317	1.962
	Hs-Good	0.347	0.312	1.112	0.284	
	Soi Text	-0.054	0.064	-0.840	0.414	
	(Intercept)	0.696	0.473	1.471	0.162	0.822
	Hs-Good	0.223	0.324	0.689	0.501	
	Soi Act	-0.097	0.073	-1.316	0.208	
	(Intercept)	0.433	0.068	6.364	0.000	2.705
	N1500	0.000	0.000	-0.051	0.960	
	N500	0.000	0.000	-1.116	0.282	
	(Intercept)	0.473	0.125	3.770	0.002	3.895
	N1500	0.000	0.000	-0.373	0.714	
	DR	0.000	0.001	-0.453	0.657	
	(Intercept)	0.594	0.178	3.338	0.004	2.925
	N1500	0.000	0.000	-0.625	0.542	
	Soi Text	-0.067	0.065	-1.023	0.322	
	(Intercept)	0.938	0.320	2.936	0.010	1.176
	N1500	0.000	0.000	-0.417	0.683	
	Soi Act	-0.113	0.069	-1.638	0.122	
	(Intercept)	0.517	0.123	4.186	0.001	1.991
	N500	0.000	0.000	-1.352	0.196	
	DR	-0.001	0.001	-0.781	0.447	
	(Intercept)	0.625	0.168	3.725	0.002	0.993
	N500	0.000	0.000	-1.461	0.165	
	Soi Text	-0.076	0.062	-1.225	0.240	
	(Intercept)	0.961	0.304	3.164	0.006	-0.712
	N500	0.000	0.000	-1.361	0.194	
	Soi Act	-0.115	0.065	-1.772	0.097	
	(Intercept)	0.604	0.191	3.156	0.007	3.116
	DR	0.000	0.001	-0.477	0.640	
	Soi Text	-0.060	0.066	-0.899	0.383	
	(Intercept)	0.960	0.324	2.961	0.010	1.185
	DR	0.000	0.001	-0.408	0.689	
	Soi Act	-0.112	0.069	-1.612	0.128	
	(Intercept)	1.075	0.374	2.879	0.012	0.818
	Soi Text	0.078	0.113	0.692	0.500	
	Soi Act	-0.188	0.124	-1.517	0.150	
W	Soi Pot	-0.034	0.023	-1.499	0.153	-32.398
	YE	-0.008	0.003	-2.203	0.043	-34.800
	Soi Text	-0.026	0.026	-1.024	0.321	-31.176
	Soi Act	-0.025	0.029	-0.871	0.397	-30.867
	Soil Thick	0.034	0.038	0.901	0.381	-30.924
	LST	0.039	0.016	2.378	0.030	-35.481
	GI	0.001	0.000	2.045	0.058	-34.212
	(Intercept)	1.057	0.099	10.624	0.000	-33.074

	Estimate	STD Error	F Value	P Value	Aic
Soi Pot	-0.012	0.026	-0.479	0.639	
YE	-0.006	0.004	-1.550	0.142	
(Intercept)	1.129	0.110	10.260	0.000	-30.695
Soi Pot	-0.055	0.048	-1.149	0.268	
Soi Text	0.026	0.053	0.499	0.625	
(Intercept)	1.049	0.133	7.888	0.000	-30.924
Soi Pot	-0.059	0.044	-1.348	0.198	
Soi Act	0.035	0.053	0.667	0.515	
(Intercept)	1.051	0.113	9.260	0.000	-31.540
Soi Pot	-0.035	0.023	-1.532	0.146	
Soil Thick	0.036	0.036	0.991	0.337	
(Intercept)	-0.095	0.568	-0.168	0.869	-35.208
Soi Pot	-0.026	0.021	-1.229	0.238	
LST	0.035	0.016	2.144	0.049	
(Intercept)	1.066	0.099	10.795	0.000	-32.821
Soi Pot	-0.018	0.025	-0.719	0.483	
GI	0.000	0.000	1.470	0.162	
(Intercept)	1.023	0.064	16.076	0.000	-32.849
YE	-0.007	0.004	-1.843	0.085	
Soi Text	-0.005	0.027	-0.201	0.844	
(Intercept)	1.027	0.127	8.081	0.000	-32.820
YE	-0.007	0.004	-1.919	0.074	
Soi Act	-0.004	0.029	-0.128	0.900	
(Intercept)	0.986	0.073	13.434	0.000	-32.978
YE	-0.007	0.004	-1.947	0.071	
Soil Thick	0.014	0.036	0.385	0.705	
(Intercept)	-0.044	0.534	-0.082	0.936	-36.980
YE	-0.006	0.003	-1.794	0.093	
LST	0.031	0.016	1.980	0.066	
(Intercept)	1.017	0.037	27.762	0.000	-32.882
YE	-0.011	0.015	-0.755	0.462	
GI	0.000	0.001	-0.262	0.797	
(Intercept)	1.035	0.162	6.373	0.000	-29.178
Soi Text	-0.025	0.049	-0.511	0.617	
Soi Act	-0.002	0.054	-0.036	0.972	
(Intercept)	0.975	0.106	9.170	0.000	-29.719
Soi Text	-0.022	0.027	-0.823	0.423	
Soil Thick	0.026	0.039	0.677	0.508	
(Intercept)	-0.237	0.551	-0.430	0.673	-34.667
Soi Text	-0.023	0.023	-1.011	0.328	
LST	0.038	0.016	2.313	0.035	
(Intercept)	1.026	0.064	15.984	0.000	-32.489
Soi Text	-0.012	0.026	-0.483	0.636	
GI	0.001	0.000	1.741	0.102	
(Intercept)	1.013	0.162	6.252	0.000	-29.533

		Estimate	STD Error	F Value	P Value	Aic
	Soi Act	-0.021	0.030	-0.719	0.483	
	Soil Thick	0.029	0.039	0.752	0.464	
	(Intercept)	-0.202	0.568	-0.356	0.727	-34.329
	Soi Act	-0.022	0.026	-0.851	0.408	
	LST	0.038	0.017	2.306	0.036	
	(Intercept)	1.042	0.128	8.175	0.000	-32.364
	Soi Act	-0.010	0.028	-0.357	0.726	
	GI	0.001	0.000	1.794	0.093	
	(Intercept)	-0.373	0.546	-0.684	0.505	-34.596
	Soil Thick	0.032	0.033	0.979	0.343	
	LST	0.039	0.016	2.357	0.032	
	(Intercept)	0.964	0.069	13.893	0.000	-32.540
	Soil Thick	0.019	0.036	0.525	0.607	
	GI	0.001	0.000	1.827	0.088	
	(Intercept)	-0.058	0.549	-0.105	0.918	-36.184
	LST	0.032	0.016	1.924	0.074	
	GI	0.000	0.000	1.559	0.140	
SIZE A	HS-Bad	0.229	0.404	0.566	0.579	-18.966
	Soil Thick	0.113	0.045	2.524	0.023	-24.643
	GI	0.001	0.000	1.150	0.267	-20.038
	N500	0.000	0.000	-1.119	0.280	-19.965
	YE	-0.007	0.005	-1.345	0.197	-20.537
	DR	-0.001	0.000	-1.777	0.095	-21.852
	NDMI Abr	-0.657	0.376	-1.750	0.099	-21.762
	(Intercept)	-0.127	0.082	-1.550	0.142	-23.314
	HS-Bad	0.264	0.350	0.755	0.462	
	Soil Thick	0.114	0.045	2.519	0.024	
	(Intercept)	0.094	0.044	2.156	0.048	-18.303
	HS-Bad	0.190	0.404	0.472	0.644	
	GI	0.000	0.000	1.075	0.299	
	(Intercept)	0.076	0.034	2.223	0.042	-19.275
	HS-Bad	0.447	0.420	1.064	0.304	
	N500	0.000	0.000	-1.433	0.172	
	(Intercept)	0.110	0.050	2.210	0.043	-18.703
	HS-Bad	0.150	0.403	0.372	0.715	
	YE	-0.007	0.005	-1.233	0.237	
	(Intercept)	0.172	0.074	2.329	0.034	-19.856
	HS-Bad	0.025	0.405	0.061	0.952	
	DR	-0.001	0.000	-1.616	0.127	
	(Intercept)	-0.084	0.090	-0.931	0.367	-23.295
	Soil Thick	0.105	0.047	2.256	0.040	
	GI	0.000	0.000	0.744	0.469	
	(Intercept)	-0.103	0.077	-1.344	0.199	-25.010
	Soil Thick	0.116	0.043	2.681	0.017	
	N500	0.000	0.000	-1.452	0.167	

		Estimate	STD Error	F Value	P Value	Aic
	(Intercept)	-0.070	0.096	-0.736	0.473	-23.429
	Soil Thick	0.102	0.047	2.164	0.047	
	YE	-0.004	0.005	-0.819	0.426	
	(Intercept)	-0.015	0.101	-0.150	0.882	-25.095
	Soil Thick	0.099	0.044	2.252	0.040	
	DR	0.000	0.000	-1.480	0.160	
	(Intercept)	0.108	0.039	2.733	0.015	-18.793
	GI	0.000	0.000	0.841	0.414	
	N500	0.000	0.000	-0.802	0.435	
	(Intercept)	0.136	0.054	2.530	0.023	-18.956
	GI	-0.001	0.002	-0.595	0.561	
	YE	-0.020	0.022	-0.886	0.389	
	(Intercept)	0.189	0.065	2.917	0.011	-20.904
	GI	0.000	0.000	0.950	0.357	
	DR	-0.001	0.000	-1.609	0.128	
	(Intercept)	0.121	0.044	2.724	0.016	-19.214
	N500	0.000	0.000	-0.758	0.460	
	YE	-0.006	0.005	-1.038	0.316	
	(Intercept)	0.198	0.063	3.121	0.007	-22.007
	N500	0.000	0.000	-1.381	0.187	
	DR	-0.001	0.000	-1.943	0.071	
	(Intercept)	0.200	0.066	3.022	0.009	-21.337
	YE	-0.006	0.005	-1.136	0.274	
	DR	-0.001	0.000	-1.589	0.133	
SIZE B	Soi Act	0.190	0.085	2.244	0.039	8.069
	Soi Pot	0.140	0.072	1.947	0.069	9.169
	Soi Text	0.131	0.082	1.602	0.129	10.317
	N500	0.000	0.000	1.438	0.170	10.809
	HS-Medium	0.765	0.396	1.931	0.071	9.225
	N1500	0.000	0.000	1.320	0.205	11.136
	YE	0.018	0.012	1.505	0.152	10.612
	HS-Good	-0.721	0.389	-1.854	0.082	9.494
	NDMI Abr	1.373	0.925	1.485	0.157	10.671
	(Intercept)	-0.167	0.415	-0.402	0.693	10.024
	Soi Act	0.163	0.165	0.992	0.337	
	Soi Pot	0.026	0.136	0.194	0.849	
	(Intercept)	-0.260	0.481	-0.541	0.597	9.952
	Soi Act	0.232	0.160	1.451	0.167	
	Soi Text	-0.045	0.145	-0.313	0.759	
	(Intercept)	-0.214	0.379	-0.565	0.581	7.272
	Soi Act	0.188	0.081	2.324	0.035	
	N500	0.000	0.000	1.588	0.133	
	(Intercept)	-0.109	0.396	-0.276	0.786	8.470
	Soi Act	0.145	0.092	1.575	0.136	
	HS-Medium	0.492	0.417	1.181	0.256	

	Estimate	STD Error	F Value	P Value	Aic
(Intercept)	-0.182	0.391	-0.466	0.648	8.443
Soi Act	0.178	0.084	2.114	0.052	
N1500	0.000	0.000	1.191	0.252	
(Intercept)	-0.111	0.410	-0.271	0.790	9.310
Soi Act	0.162	0.093	1.738	0.103	
YE	0.010	0.012	0.804	0.434	
(Intercept)	0.325	0.586	0.555	0.587	8.520
Soi Act	0.149	0.091	1.641	0.122	
Hs-Good	-0.466	0.401	-1.161	0.264	
(Intercept)	0.092	0.352	0.260	0.798	11.159
Soi Pot	0.153	0.153	0.999	0.334	
Soi Text	-0.015	0.168	-0.091	0.929	
(Intercept)	0.073	0.300	0.244	0.811	8.608
Soi Pot	0.138	0.069	1.986	0.066	
N500	0.000	0.000	1.514	0.151	
(Intercept)	0.106	0.304	0.349	0.732	9.126
Soi Pot	0.103	0.076	1.362	0.193	
HS-Medium	0.557	0.415	1.343	0.199	
(Intercept)	0.098	0.309	0.317	0.756	9.693
Soi Pot	0.129	0.072	1.778	0.096	
N1500	0.000	0.000	1.132	0.275	
(Intercept)	0.170	0.336	0.506	0.620	10.741
Soi Pot	0.112	0.087	1.282	0.219	
YE	0.008	0.014	0.601	0.557	
(Intercept)	0.603	0.451	1.338	0.201	8.706
Soi Pot	0.114	0.072	1.585	0.134	
Hs-Good	-0.569	0.384	-1.483	0.159	
(Intercept)	0.278	0.209	1.329	0.204	8.909
Soi Text	0.148	0.077	1.905	0.076	
N500	0.000	0.000	1.768	0.097	
(Intercept)	0.271	0.215	1.262	0.226	9.523
Soi Text	0.099	0.081	1.220	0.241	
HS-Medium	0.640	0.404	1.587	0.133	
(Intercept)	0.286	0.216	1.325	0.205	9.939
Soi Text	0.135	0.079	1.707	0.108	
N1500	0.000	0.000	1.456	0.166	
(Intercept)	0.381	0.217	1.753	0.100	11.342
Soi Text	0.095	0.091	1.047	0.312	
YE	0.012	0.013	0.914	0.375	
(Intercept)	0.853	0.356	2.399	0.030	9.273
Soi Text	0.110	0.079	1.404	0.181	
Hs-Good	-0.636	0.382	-1.663	0.117	
(Intercept)	0.482	0.129	3.744	0.002	9.953
N500	0.000	0.000	1.048	0.311	
HS-Medium	0.656	0.409	1.606	0.129	

		Estimate	STD Error	F Value	P Value	Aic
	(Intercept)	0.619	0.088	7.004	0.000	12.099
	N500	0.000	0.000	0.943	0.361	
	N1500	0.000	0.000	0.777	0.449	
	(Intercept)	0.573	0.104	5.530	0.000	11.347
	N500	0.000	0.000	1.045	0.313	
	YE	0.014	0.013	1.126	0.278	
	(Intercept)	1.066	0.314	3.391	0.004	10.744
	N500	0.000	0.000	0.799	0.437	
	Hs-Good	-0.581	0.430	-1.350	0.197	
	(Intercept)	0.482	0.141	3.416	0.004	11.224
	HS-Medium	0.775	0.598	1.296	0.214	
	N1500	0.000	0.000	-0.023	0.982	
	(Intercept)	0.448	0.135	3.316	0.005	10.203
	HS-Medium	0.624	0.426	1.466	0.163	
	YE	0.012	0.013	0.936	0.364	
	(Intercept)	0.727	0.876	0.830	0.420	11.130
	HS-Medium	0.524	0.948	0.553	0.588	
	Hs-Good	-0.260	0.923	-0.282	0.782	
	(Intercept)	0.520	0.112	4.639	0.000	10.724
	N1500	0.000	0.000	1.288	0.217	
	YE	0.017	0.012	1.466	0.163	
	(Intercept)	1.161	0.453	2.561	0.022	11.487
	N1500	0.000	0.000	0.072	0.944	
	Hs-Good	-0.691	0.576	-1.199	0.249	
	(Intercept)	1.020	0.311	3.278	0.005	10.125
	YE	0.013	0.012	1.089	0.294	
	Hs-Good	-0.600	0.402	-1.491	0.157	
SIZE D	GI	0.001	0.001	0.728	0.477	2.943
	YE	-0.011	0.010	-1.177	0.256	2.035
	N500	0.000	0.000	-1.183	0.254	2.020
	N1500	0.000	0.000	-1.013	0.326	2.411
	HS-Good	0.533	0.301	1.768	0.096	0.318
	HS-Medium	-0.523	0.312	-1.678	0.113	0.613
	Soi Text	-0.132	0.059	-2.220	0.041	-1.303
	Soi Pot	-0.141	0.051	-2.779	0.013	-3.558
	Soi Act	-0.177	0.060	-2.939	0.010	-4.240
	NDMI Abr	-0.688	0.738	-0.932	0.365	2.579
	(Intercept)	0.390	0.092	4.213	0.001	0.451
	GI	-0.006	0.003	-1.818	0.089	
	YE	-0.079	0.038	-2.062	0.057	
	(Intercept)	0.268	0.074	3.620	0.003	3.832
	GI	0.000	0.001	0.397	0.697	
	N500	0.000	0.000	-0.977	0.344	
	(Intercept)	0.296	0.084	3.544	0.003	3.856
	GI	0.001	0.001	0.685	0.504	

	Estimate	STD Error	F Value	P Value	Aic
N1500	0.000	0.000	-0.966	0.349	
(Intercept)	-0.102	0.236	-0.432	0.672	2.132
GI	0.000	0.001	0.394	0.699	
Hs-Good	0.505	0.317	1.592	0.132	
(Intercept)	0.377	0.107	3.520	0.003	2.479
GI	0.000	0.001	0.334	0.743	
HS-Medium	-0.494	0.333	-1.483	0.159	
(Intercept)	0.551	0.161	3.417	0.004	0.680
GI	0.000	0.001	0.122	0.905	
Soi Text	-0.129	0.064	-2.002	0.064	
(Intercept)	0.844	0.234	3.609	0.003	-1.770
GI	0.000	0.001	-0.421	0.680	
Soi Pot	-0.152	0.058	-2.604	0.020	
(Intercept)	1.038	0.294	3.526	0.003	-2.240
GI	0.000	0.001	0.020	0.984	
Soi Act	-0.177	0.065	-2.712	0.016	
(Intercept)	0.300	0.083	3.633	0.002	3.164
YE	-0.009	0.010	-0.855	0.406	
N500	0.000	0.000	-0.863	0.402	
(Intercept)	0.331	0.090	3.670	0.002	2.960
YE	-0.011	0.010	-1.122	0.279	
N1500	0.000	0.000	-0.961	0.352	
(Intercept)	-0.046	0.246	-0.188	0.853	1.628
YE	-0.007	0.010	-0.766	0.456	
Hs-Good	0.465	0.318	1.465	0.164	
(Intercept)	0.389	0.108	3.610	0.003	2.097
YE	-0.007	0.010	-0.660	0.519	
HS-Medium	-0.444	0.340	-1.306	0.211	
(Intercept)	0.548	0.161	3.410	0.004	0.539
YE	-0.004	0.010	-0.364	0.721	
Soi Text	-0.121	0.067	-1.793	0.093	
(Intercept)	0.828	0.239	3.469	0.003	-1.583
YE	0.001	0.010	0.144	0.888	
Soi Pot	-0.145	0.062	-2.344	0.033	
(Intercept)	1.022	0.297	3.445	0.004	-2.335
YE	-0.003	0.009	-0.282	0.782	
Soi Act	-0.170	0.067	-2.524	0.023	
(Intercept)	0.271	0.070	3.870	0.002	3.654
N500	0.000	0.000	-0.803	0.435	
N1500	0.000	0.000	-0.555	0.587	
(Intercept)	-0.073	0.246	-0.295	0.772	1.946
N500	0.000	0.000	-0.559	0.584	
Hs-Good	0.456	0.337	1.353	0.196	
(Intercept)	0.370	0.103	3.602	0.003	1.820
N500	0.000	0.000	-0.822	0.424	

	Estimate	STD Error	F Value	P Value	Aic
HS-Medium	-0.455	0.326	-1.396	0.183	
(Intercept)	0.615	0.153	4.015	0.001	-2.334
N500	0.000	0.000	-1.659	0.118	
Soi Text	-0.143	0.057	-2.520	0.024	
(Intercept)	0.837	0.214	3.911	0.001	-3.608
N500	0.000	0.000	-1.345	0.199	
Soi Pot	-0.139	0.049	-2.813	0.013	
(Intercept)	1.061	0.274	3.875	0.001	-4.463
N500	0.000	0.000	-1.404	0.181	
Soi Act	-0.176	0.058	-3.005	0.009	
(Intercept)	-0.213	0.351	-0.609	0.552	2.230
N1500	0.000	0.000	0.271	0.790	
Hs-Good	0.619	0.445	1.390	0.185	
(Intercept)	0.377	0.111	3.403	0.004	2.552
N1500	0.000	0.000	0.224	0.825	
HS-Medium	-0.600	0.470	-1.277	0.221	
(Intercept)	0.603	0.160	3.781	0.002	-1.005
N1500	0.000	0.000	-1.220	0.241	
Soi Text	-0.134	0.058	-2.295	0.037	
(Intercept)	0.820	0.221	3.704	0.002	-2.292
N1500	0.000	0.000	-0.790	0.442	
Soi Pot	-0.135	0.052	-2.601	0.020	
(Intercept)	1.040	0.284	3.666	0.002	-3.114
N1500	0.000	0.000	-0.864	0.401	
Soi Act	-0.171	0.061	-2.790	0.014	
(Intercept)	0.001	0.685	0.002	0.998	2.262
Hs-Good	0.392	0.721	0.543	0.595	
HS-Medium	-0.160	0.741	-0.216	0.832	
(Intercept)	0.215	0.259	0.830	0.420	-2.097
Hs-Good	0.442	0.279	1.587	0.133	
Soi Text	-0.117	0.057	-2.042	0.059	
(Intercept)	0.494	0.320	1.544	0.143	-3.625
Hs-Good	0.368	0.272	1.351	0.197	
Soi Pot	-0.124	0.051	-2.422	0.029	
(Intercept)	0.745	0.422	1.765	0.098	-3.265
Hs-Good	0.271	0.289	0.937	0.363	
Soi Act	-0.153	0.066	-2.335	0.034	
(Intercept)	0.610	0.160	3.813	0.002	-1.145
HS-Medium	-0.381	0.300	-1.271	0.223	
Soi Text	-0.112	0.060	-1.866	0.082	
(Intercept)	0.816	0.220	3.713	0.002	-2.553
HS-Medium	-0.277	0.300	-0.923	0.371	
Soi Pot	-0.122	0.055	-2.233	0.041	
(Intercept)	1.006	0.289	3.486	0.003	-2.914
HS-Medium	-0.230	0.304	-0.757	0.461	

		Estimate	STD Error	F Value	P Value	Aic
	Soi Act	-0.156	0.067	-2.322	0.035	
	(Intercept)	0.829	0.247	3.356	0.004	-1.577
	Soi Text	0.015	0.118	0.125	0.902	
	Soi Pot	-0.152	0.107	-1.421	0.176	
	(Intercept)	1.057	0.343	3.081	0.008	-2.251
	Soi Text	0.010	0.103	0.097	0.924	
	Soi Act	-0.186	0.114	-1.634	0.123	
	(Intercept)	1.008	0.291	3.464	0.003	-2.713
	Soi Pot	-0.060	0.095	-0.632	0.537	
	Soi Act	-0.115	0.116	-0.997	0.335	
SIZE E	DR	0.000	0.000	-1.764	0.097	-96.153
	Soil Thick	0.005	0.007	0.833	0.417	-93.719
	(Intercept)	0.012	0.015	0.790	0.442	-94.481
	DR	0.000	0.000	-1.577	0.136	
	Soil Thick	0.003	0.006	0.525	0.607	
NMS1	Soil_Text	0.5478	0.1592	3.442	0.00335	34.263
	Soil_Pot	0.4436	0.1555	2.853	0.0115	36.834
	Soil_Act	0.423	0.206	2.053	0.0568	40.027
	NDMI Apr	2.6698	2.2519	1.186	0.253	42.721
	(Intercept)	-0.70706	0.69745	-1.014	0.327	35.769
	Soi_Text	-0.05943	0.33261	-0.179	0.861	
	Soi_Pot	0.20265	0.30251	0.67	0.513	
	(Intercept)	0.6676	0.9585	0.697	0.497	34.744
	Soi_Text	0.4169	0.2889	1.443	0.17	
	Soi_Act	-0.3708	0.3186	-1.164	0.263	
	(Intercept)	0.1969	0.78	0.252	0.8042	32.776
	Soi_Pot	0.5141	0.2553	2.014	0.0623	
	Soi_Act	-0.5135	0.3095	-1.659	0.1179	
NMS 2	DR	-0.002086	0.00157	-1.329	0.202	33.206
	N1500	-0.00001097	0.000008341	-1.315	0.207	33.245
	Soil_Pot	0.1555	0.1429	1.088	0.293	33.807
	NDMI Apr	-1.141	1.7993	-0.634	0.535	34.644
	(Intercept)	0.3497	0.2916	1.199	0.249	34.271
	DR	-0.001545	0.001692	-0.913	0.376	
	N1500	-0.00000803	0.00000898	-0.894	0.385	
	(Intercept)	-0.392194	0.61682	-0.636	0.534	33.158
	DR	-0.002387	0.001548	-1.542	0.144	
	Soi_Pot	0.186365	0.138608	1.345	0.199	
	(Intercept)	-0.6391	0.5934	-1.077	0.298	33.202
	N1500	-0.00001258	0.000008227	-1.529	0.147	
	Soi_Pot	0.1864	0.1388	1.343	0.199	
NMS 3	GI	0.002251	0.001652	1.363	0.192	27.471
	YE	-0.02534	0.01947	-1.302	0.211	27.635
	DR	-0.0009957	0.001392	-0.715	0.485	28.881
	N 500m	-0.0002589	0.0001773	-1.46	0.164	27.195

	Estimate	STD Error	F Value	P Value	Aic
N1500	-0.00001073	0.00000701	-1.53	0.145	26.988
HS-Medium	-1.0119	0.6472	-1.563	0.138	26.888
HS-Bad	1.35832	1.5124	0.898	0.382	28.562
Soil_Pot	-0.1856	0.1178	-1.575	0.135	26.852
NDMI Apr	-2.524	1.4239	-1.773	0.0953	26.22
NDMI Jul	-1.4739	1.0491	-1.405	0.179	27.353
(Intercept)	0.117816	0.207023	0.569	0.578	29.465
GI	0.002752	0.007294	0.377	0.711	
YE	0.006037	0.085546	0.071	0.945	
(Intercept)	0.2423117	0.2604602	0.93	0.367	29.133
GI	0.0021144	0.0017097	1.237	0.235	
DR	-0.0007388	0.0013852	-0.533	0.602	
(Intercept)	0.150888	0.1451364	1.04	0.315	28.089
GI	0.0016802	0.001723	0.975	0.345	
N500	-0.0002039	0.0001863	-1.094	0.291	
(Intercept)	0.2437	0.1587	1.535	0.146	26.921
GI	0.00215	0.001591	1.351	0.197	
N1500	-0.00001034	0.000006842	-1.511	0.152	
(Intercept)	0.329493	0.215804	1.527	0.148	27.712
GI	0.001696	0.001685	1.007	0.33	
HS-Medium	-0.832739	0.670989	-1.241	0.234	
(Intercept)	0.072593	0.161746	0.449	0.66	28.721
GI	0.002132	0.001678	1.271	0.223	
HS-Bad	1.190469	1.489994	0.799	0.437	
(Intercept)	0.671209	0.537966	1.248	0.231	28.199
GI	0.001375	0.001847	0.744	0.468	
Soi_Pot	-0.140461	0.134012	-1.048	0.311	
(Intercept)	0.272599	0.2701796	1.009	0.329	29.304
YE	-0.0236424	0.0201788	-1.172	0.26	
DR	-0.0007352	0.0013939	-0.527	0.606	
(Intercept)	0.1751141	0.1654795	1.058	0.307	28.212
YE	-0.0185863	0.0202593	-0.917	0.373	
N500	-0.0002075	0.0001868	-1.111	0.284	
(Intercept)	0.2732	0.1768	1.545	0.143	27.148
YE	-0.02387	0.01879	-1.271	0.223	
N1500	-0.00001027	0.000006889	-1.491	0.157	
(Intercept)	0.3341	0.22201	1.505	0.153	28.101
YE	-0.01688	0.02061	-0.819	0.426	
HS-Medium	-0.80831	0.69961	-1.155	0.266	
(Intercept)	0.10329	0.18782	0.55	0.59	29.036
YE	-0.02307	0.02003	-1.152	0.267	
HS-Bad	1.08085	1.5164	0.713	0.487	
(Intercept)	0.68422	0.55006	1.244	0.233	28.482
YE	-0.01291	0.02313	-0.558	0.585	
Soi_Pot	-0.14252	0.14306	-0.996	0.335	

	Estimate	STD Error	F Value	P Value	Aic
(Intercept)	0.2691014	0.2563021	1.05	0.31	28.294
DR	-0.001179	0.0013433	-0.878	0.394	
N500	-0.000273	0.0001793	-1.523	0.149	
(Intercept)	0.1707	0.2514	0.679	0.508	28.934
DR	-0.0003121	0.001459	-0.214	0.833	
N1500	-0.00001014	0.000007743	-1.309	0.21	
(Intercept)	0.3642674	0.2873854	1.268	0.224	28.669
DR	-0.0005929	0.0013822	-0.429	0.674	
HS-Medium	-0.95124	0.6792657	-1.4	0.182	
(Intercept)	0.0656045	0.2979781	0.22	0.829	30.317
DR	-0.0006753	0.0014894	-0.453	0.657	
HS-Bad	1.1277231	1.6326546	0.691	0.5	
(Intercept)	0.8623659	0.5423751	1.59	0.133	28.527
DR	-0.0007109	0.0013609	-0.522	0.609	
Soi_Pot	-0.1764057	0.1218795	-1.447	0.168	
(Intercept)	0.07041	0.1482	0.475	0.642	27.911
N1500	-0.00001084	0.000007028	-1.543	0.144	
HS-Bad	1.396	1.451	0.962	0.351	
(Intercept)	0.2411	0.2281	1.057	0.307	28.51
N1500	-0.000005891	0.00001044	-0.564	0.581	
HS-Medium	-0.6142	0.9665	-0.636	0.535	
(Intercept)	0.7965	0.4964	1.605	0.129	26.774
N1500	-0.000009323	0.000006882	-1.355	0.196	
Soi_Pot	-0.1627	0.1161	-1.401	0.181	
(Intercept)	0.2209	0.2331	0.947	0.358	28.336
HS-Bad	1.0174	1.4883	0.684	0.505	
HS-Medium	-0.9375	0.6672	-1.405	0.18	
(Intercept)	0.6766	0.5549	1.219	0.242	28.485
HS-Bad	0.8461	1.5222	0.556	0.587	
Soi_Pot	-0.1684	0.1244	-1.354	0.196	
(Intercept)	0.7816	0.507	1.542	0.144	27.541
HS-Medium	-0.7371	0.6924	-1.065	0.304	
Soi_Pot	-0.1362	0.1262	-1.08	0.297	